Muş Alparslan Üniversitesi
Teknik Bilimler Meslek Yüksekokulu

MUŞ ALPARSLAN ÜNİVERSİTESİ / MUŞ ALPARSLAN UNIVERSITY

www.alparslan.edu.tr

e-ISSN: 3023-7777

Ekim/October 2024

Cilt/Volume: 1

Sayı/Issue: 2

HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ

JOURNAL of
HENDESE TECHNICAL SCIENCES and ENGINEERING

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JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING

YIL/YEAR	CİLT/VOLUME	SAYI/ISSUE
2024	1	2

e-ISSN

3023-7777

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HENDESE, online yayınlanan bir bilimsel dergidir ve yılda 2 defa yayınlanır.
HENDESE is a scientific journal published online and is published twice a year.

1. Periyot	**1. Period**
Kasım - Nisan	November - April
2. Periyot	**2. Period**
Mayıs - Ekim	May - October

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e-ISSN	**e-ISSN**
3023-7777	*3023-7777*

Yayıncı	**Publisher**
Muş Alparslan Üniversitesi	*Muş Alparslan University*

İletişim **Contact**

Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye

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https://dergipark.org.tr/en/pub/hendese/board

e-ISSN: 3023-7777

Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

İÇİNDEKİLER / CONTENTS

ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
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https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

Response of the Turkish Ionosphere to Geomagnetic Storms During the 24th Solar Cycle

Mehmet YASAR[1]

[1]*Science Faculty, Fırat University, Elazig, TÜRKİYE*

mehmetyasar@firat.edu.tr — ORCID 0000-0002-2758-3635

Article Information

Article Types	Research Article
Received	06 June 2024
Accepted	06 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 50-56

Cite as: Yasar, M., "Response of the Turkish Ionosphere to Geomagnetic Storms During the 24th Solar Cycle", Hendese, Vol. 1, Issue 2, Pages 50-56, 2024.

Corresponding Author: Mehmet YASAR

https://doi.org/10.5281/zenodo.13996448

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
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Response of the Turkish Ionosphere to Geomagnetic Storms During the 24th Solar Cycle

Mehmet YASAR[*1]

[*1]*Science Faculty, Fırat University, Elazig, TÜRKİYE*

(**Received:** 06.06.2024, **Accepted:** 06.10.2024, **Published Online:** 27.10.2024)

Keywords
Geomagnetic storms,
Ionosphere,
DROT,
Solar activity,
Traveling ionospheric disturbances (TIDs)

ABSTRACT

The Earth's ionosphere, a haven for charged particles within the atmosphere, is susceptible to energetic excitations from space weather. When geomagnetic storms erupt, triggered by solar activity, a cascade of charged particles rushes towards our planet. These charged particles, among other factors, have dynamic and disruptive effects on Earth's ionosphere. The foremost among these effects are significant fluctuations in the ionospheric electron density during geomagnetic storms. This study investigates the effects of 54 geomagnetic storms of different magnitudes on the Turkish ionosphere during the 24th Solar Cycle using the differential rate of total electron content (DROT) method. The study was conducted for the TUBITAK station. The results indicate that both medium- and large-scale traveling ionospheric disturbances (TIDs) occurred in the Turkish ionosphere during these geomagnetic storms. However, it was also observed that no ionospheric disturbances occurred during some geomagnetic storms. The study demonstrates that the DROT method requires careful application in detecting ionospheric disturbances.

Corresponding Author: mehmetyasar@firat.edu.tr
Volume: 1 **Issue:** 2

Cite as: Yasar, M., "Response of the Turkish Ionosphere to Geomagnetic Storms During the 24th Solar Cycle", Hendese, Vol. 1, Issue 2, Pages 50-56, 2024.

Doi: 10.5281/zenodo.13996448

1. INTRODUCTION

The ionosphere is a region of the Earth's upper atmosphere that extends from approximately 50 km to about 1000 km in altitude, encompassing the mesosphere and thermosphere regions. It is named the ionosphere primarily due to the high abundance of ions and free electrons generated by the ionization of atmospheric gases, largely caused by intense ultraviolet (UV) radiation from the Sun [1-4].

The ionosphere is divided into several layers, each named according to the primary ionizing substance present in the layer. Layers from the lowest to highest altitudes are the D, E, and F layers (which are further subdivided into the F1 and F2 layers). The layers where molecular ions dominate and chemical processes are important are the D and E regions, respectively. Although the D region has a complex structure in terms of water ions, ternary reactions, and positive and negative ions, the E region is not complex in terms of its chemical structure. In the F1 region, ion-atom transformations and transport dominate, and in the F2 region, ionization is seen to increase as a result of transport and chemical losses in the plasma [2, 5].

The ionosphere plays a crucial role in the propagation of radio waves by reflecting certain frequencies back to the Earth, thus enabling long-distance communication via radio signals. Due to its significant role, continuous monitoring of the ionosphere is necessary, and measures must be taken to ensure uninterrupted radiowave and satellite communications. To achieve this, it is important to detect ionospheric disturbances and take measures to mitigate them [6 - 12].

Traveling ionospheric disturbances (TIDs), which are ionospheric disturbances that occur in the ionosphere, are variations in electron density that spread horizontally along the ionospheric plasma. These disturbances are often associated with changes in the neutral atmosphere, including atmospheric gravity waves, and can have significant effects on radio wave propagation. TIDs can affect radio wave propagation in the ionosphere. Changes in electron density caused by TIDs can cause scintillation in radio signals, affecting the quality and reliability of communication and navigation systems. Understanding and monitoring TIDs are crucial for predicting and mitigating these effects [13 - 17].

TIDs in the ionosphere are typically generated by atmospheric gravity waves originating from the lower atmosphere, especially the troposphere and stratosphere. As these waves propagate upward, they can induce changes in ionospheric electron density. TIDs can travel over large distances and at different speeds depending on their sources and the characteristics of the neutral atmosphere. They exhibit a frequency range and various periods ranging from a few minutes to several hours [13 - 19]. Shorter periods are associated with gravity waves originating from the lower atmosphere, while longer periods may be linked to solar-induced variations. TIDs can be influenced by space weather events such as solar flares and geomagnetic storms. During geomagnetic storms, there is an intense energy input from the magnetosphere to the Earth's upper atmosphere. This energy input causes ionospheric disturbances such as temperature, wind, and density. The increased magnetospheric flux energy during the geomagnetic storm period creates ionospheric disturbances that expand toward the equator [20-21]. Changes in ionospheric conditions due to TIDs can impact satellite communications, GPS navigation, and other ionosphere-dependent technologies.

TIDs are evaluated in two groups according to the characteristics of the oscillations. Large-Scale Traveling Ionospheric Disturbances (LSTIDs) and Medium-Scale Traveling Ionospheric Disturbances (MSTIDs) (Francis 1974). Both LSTIDs and MSTIDs have been observed to travel thousands of kilometers and reach speeds of hundreds of kilometers per hour [22 - 24].

Scientists use various observation techniques to study TIDs in the ionosphere. Ground-based instruments, such as ionosondes and radar systems, can provide valuable data on the vertical and horizontal distribution of the electron density. Global Navigation Satellite System (GNSS) receivers, which use signals from satellites, are also used to detect TIDs by monitoring fluctuations in received signals [11, 25-28].

In this work, the response of the Turkey ionosphere, located in the mid-latitude region, to geomagnetic storms occurring during the 24th solar cycle is investigated using the differential rate of total electron content (DROT) method commonly employed in many studies in the literature. The total electron content (TEC) data from the TUBI station of the Turkey National GNSS Network (TUSAGA-Aktif) are utilized for this purpose. TEC data was obtained using the IONOLAB-TEC software provided by the Hacettepe University Engineering Faculty.

2. MATERIAL AND METHOD

2.1. Obtaining Ionolab-Tec Data

IONOLAB-TEC (I-TEC) values were obtained for the coordinates of the TUBI station at temporal resolution, i.e., 30 s, through the IONOLAB-TEC/STEC software, which can be downloaded as *.exe from the website www.ionolab.org, on geomagnetically disturbed days [29, 30]. The IONOLAB service has been used and mentioned in many studies in TEC estimation and modeling. This service with a graphical interface provides comfortable use. This unique application can be accessed online by registering for free and downloading IONOLAB-TEC forecasts for different stations with appropriate files [31].

This model calculates STEC, the line integral for electron density along the raypath between the receiver and satellite station, using the IONOLAB - STEC/TEC algorithm. VTEC is obtained from STEC due to its reflection at the Ionosphere Pierce Point (IPP) in the ionosphere model consisting of a single layer (SLIM) [32]. While STEC symbolizes total activity along a single raypath between the global positioning system satellite and earth-based receiver, I-TEC combines all variability in the local zenith direction because of the different orbit positions of various satellites. IONOLAB-TEC and

IONOLAB-STEC provide reliable, accurate, and robust GPS-TEC (G-TEC) estimates for any high-latitude, mid-latitude, or equatorial global positioning system station for both disturbed and quiet days [30].

2.2. Difference of Rate of TEC (DROT)

In this work, the response of the Turkey ionosphere to a total of 54 geomagnetic storms that occurred during the 24th solar cycle was investigated using the Differential Rate of Total Electron Content (DROT) method, as detailed below. The DROT method is a proposed technique for automatically detecting ionospheric disturbances and scaling the intensity of these disturbances for further investigation. DROT is a sensitive method for amplitudes that exhibit wave behavior. In a study where the DROT method was applied to STEC data of disturbed days in the mid-latitude, it was recorded that the disturbances were detected in almost real time, even if 15-minute data were taken from the GPS station [19, 27].

Let the G-TEC values for receiver u on day d be represented as follows:

$$x_{u,d} = \left[x_{u,d}(1) + \cdots + x_{u,d}(n) + \cdots + x_{u,d}(N)\right]^T \quad (1)$$

Here, N represents the total number of G-TEC values for receiver u on day d, and T is the operator. The temporal variation of the TEC values can be observed in Figure 1-a.

One of the most commonly used methods to investigate the temporal variability of the ionosphere is the rate of TEC (ROT). The ROT method is typically used to evaluation of ionospheric perturbations. The change rate of TEC and ROT in a unit time interval is equivalent and the unit of ROT is TECU/s. In this work, the temporal derivative ROT is calculated from the TEI data as follows:

$$ROT_{u,d}(n) = \frac{\left(x_{u,d}(n+1) - x_{u,d}(n)\right)}{\Delta t} \quad (2)$$

Here, Δt represents the time interval of the samples, which is 30 s in this study. Then, we can express the obtained ROT values as follows:

$$ROT_{u,d} = \left[ROT_{u,d}(1) + \cdots + ROT_{u,d}(n) + \cdots + ROT_{u,d}(N)\right]^T \quad (3)$$

The temporal variation of the ROT values for a sample storm is shown in Figure 1-b. These values are then subjected to a median filter to address the linearity problem. Nonlinear digital filtering technique commonly used to remove or smooth noise in an image or signal is defined as median filter in Digital Signal/Image Processing. Median filters are useful in reducing random noise when the probability of noise amplitude has large tails and periodic patterns [19]. Performing operations with the help of a sliding window on the signal or image is called median filtering. To apply the median filter with the DROT method, two sliding windows of different lengths, t_f1 and t_f2, are first determined and applied to the data. In this study, the first filter of length t_f1 was applied to correct noise data due to factors unrelated to ionospheric parameters, such as signal processing, global positioning system antenna phase problems and instantaneous loss, and abrupt changes or interruptions, such as power ratios or Signal-to-Noise Ratio (SNR) or low Signal-to-Carrier Ratio (SCR). Therefore, the first filter of median is used for ROT as follows:

$$Y_{u,d} = medfilt(ROT, t_{f1}), \quad (4)$$

The median time filter of the second sliding window, t_f2, in predicting the behavior of the TEC structure is as follows and:

$$\widehat{Y_{u,d}} = medfilt\left(Y_{u,d}, t_{f2}\right) \quad (5)$$

The temporal variation of $Y_{u,d}$ and $\widehat{Y_{u,d}}$ values for a sample storm is shown in Figure 1-c.

Equation (6) shows the ROT variation, indicating that this nonlinear trend filter can correct all other potential perturbations with durations shorter than 15 minutes and longer than 4 hours [19, 27].

In reducing TEC variability that does not contribute to the ionosphere, the first falling window in the median filter length was chosen as , t_{f1}=25 to correspond to 12,5 minutes. This value corresponds broadly to the quiescent period of the mid-latitude ionosphere, as discussed by Sayin et al. (2010), Erol and Arıkan (2005) [33, 34]. The length of the second sliding window filter, , t_{f2}=504, was selected as 504, corresponding to 4,2 hours. The difference in the second level for the DROT algorithm can be obtained from Equations (4) and (5) as follows:

$$D_{u,d} = Y_{u,d} - \widehat{Y_{u,d}} \quad (6)$$

Finally, the ratio of equation (7) to equation (5) gives the DROT values in the third step. Thus;

$$DROT_{u,d} = \frac{\sqrt{\sum_{n=1}^{N}\left[D_{u,d}(n)\right]^2}}{\sqrt{\sum_{n=1}^{N}\left[Y_{u,d}(n)\right]^2}} \times 100 \quad (7)$$

an expression is derived. The temporal variation of $DROT_{u,d}$ values for a sample storm is shown in Figure 1-d.

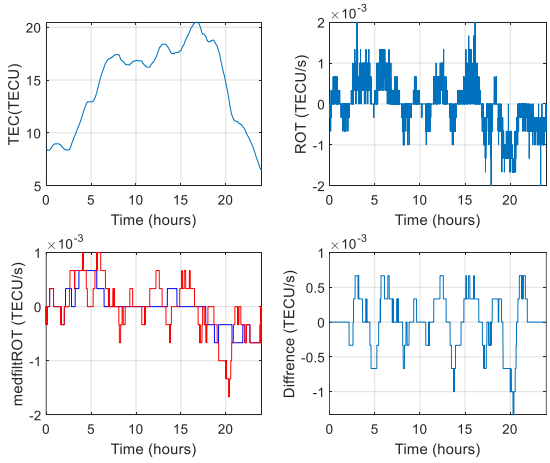

Figure 1. Temporal variations of parameters obtained using the DROT method during the geomagnetic storm on August 04, 2010. (a) Shows the variation of normalized TEC values, (b) represents the variation of ROT values, (c) shows the temporal changes of the red line $Y_{u,d}$ value and the blue line $\widehat{Y_{u,d}}$ value, and (d) shows the temporal variation of the differential rate of TEC (DROT) value.

3. RESULTS AND DISCUSSION

In this study, the response of the Turkish ionosphere to a total of 54 geomagnetic storms occurring during the 24th solar cycle was investigated using the DROT method. The Kp and Dst indices were used as geomagnetic storm indices in the study. The storms considered for this solar cycle and their relevant values are shown in Table 1. The IONOLAB-TEC values obtained from the TUBI station in the Turkey National GNSS Network were used to examine changes in the ionosphere in Turkey. The values obtained from the application of the DROT method to these IONOLAB-TEC values from this station are depicted in Figure 2.

When examining the obtained results, it can be stated that both medium-scale (MSIDs) and large-scale (LSIDs) traveling ionospheric disturbances occurred in the Turkish ionosphere during geomagnetic storms according to the DROT method. The highest disturbance, with a value of 101,95%, was observed during the geomagnetic storm on 28 May 2017. On this storm day, the Kp value reached 7, and the Dst value reached a value of -125 nT. Similarly, the lowest value obtained, with a percentage of 31,91%, occurred during the geomagnetic storm on March 17, 2013. During this storm, the Kp value was 6.7, and the Dst value was -132 nT. Studies proposing the DROT method in the literature suggest that when this value is between 50% and 70%, MSIDs occur, when it exceeds 70%, LSIDs occur, and when it is below 50%, no ionospheric disturbance occurs. Therefore, it can be stated that there was no response of the Turkish ionosphere to some of the geomagnetic storms examined in this study. This is because, respectively, for the storms on October 24 and 25, 2011, March 15, 2012, October 8, 2012, March 17, 2013, February 19, 2014, September 12, 2014, August 15, 2015, and September 20, 2015, the DROT values were 34.59, 34.95, 39.73, 38.84, 31.91, 44.97, 35.9, 44.96, and 48.95.

Table 1. Representation of Kp and Dst values and DROT values for geomagnetic storms occurring during the 24th solar cycle.

No	Day of storm	Kp max	Dst-max	DROT	No	Day of storm	Kp max	Dst-max	DROT
1	10/11/2008	6,3	-54	76,26	28	06/22/2015	8,3	-114	61,33
2	04/05/2010	7,7	-61	68,15	29	06/23/2015	7,7	-198	58,91
3	08/03/2010	6,7	-72	55,91	30	08/15/2015	6,3	-71	44,96
4	08/04/2010	6,3	-74	79,65	31	08/27/2015	6,3	-103	81,83
5	05/28/2011	6,3	-80	54,14	32	09/07/2015	6,3	-75	63,02
6	08/05/2011	7,7	-96	62,11	33	09/11/2015	7	-87	60,27
7	09/26/2011	6,3	-118	61,39	34	09/20/2015	7	-79	48,95
8	10/24/2011	7	-79	34,59	35	10/07/2015	7,3	-130	54,45
9	10/25/2011	7,3	-147	34,95	36	12/20/2015	6,7	-166	93,76
10	03/09/2012	8	-145	61,03	37	12/21/2015	6,7	-159	62,83
11	03/15/2012	6,3	-88	39,73	38	05/08/2016	6,3	-95	77,67
12	04/24/2012	6,7	-120	51,48	39	10/13/2016	6,3	-110	64,34
13	07/09/2012	6,7	-78	68,94	40	10/25/2016	6,3	-65	94,92
14	07/15/2012	7	-139	57,22	41	03/27/2017	6,3	-70	87,56
15	07/16/2012	6,3	-113	56,45	42	05/28/2017	7	-125	101,95
16	10/01/2012	6,7	-122	75,18	43	09/07/2017	7,7	-68	68,45
17	10/08/2012	6,3	-99	38,84	44	09/08/2017	8,3	-122	89,33
18	10/09/2012	6,7	-109	60,16	45	09/27/2017	6,3	-44	85,39
19	11/14/2012	6,3	-108	65,89	46	09/28/2017	6,7	-56	87,68
20	03/17/2013	6,7	-132	31,91	47	11/07/2017	6,3	-71	83,77
21	06/01/2013	7	-124	72,47	48	11/08/2017	6,3	-73	59,33
22	06/29/2013	6,3	-101	72,77	49	08/26/2018	7,3	-175	80,65
23	10/02/2013	7,7	-72	58,25	50	08/27/2018	3,3	-71	91,39
24	02/19/2014	6,3	-119	44,97	51	05/11/2019	3,7	-50	81,38

25	06/08/2014	6,3	-37	78,77	52	05/14/2019	6,3	-65	80,78
26	09/12/2014	6,3	-88	35,9	53	08/05/2019	5,3	-53	92,91
27	03/17/2015	7,7	-234	56,12	54	09/01/2019	5,3	-52	96,2

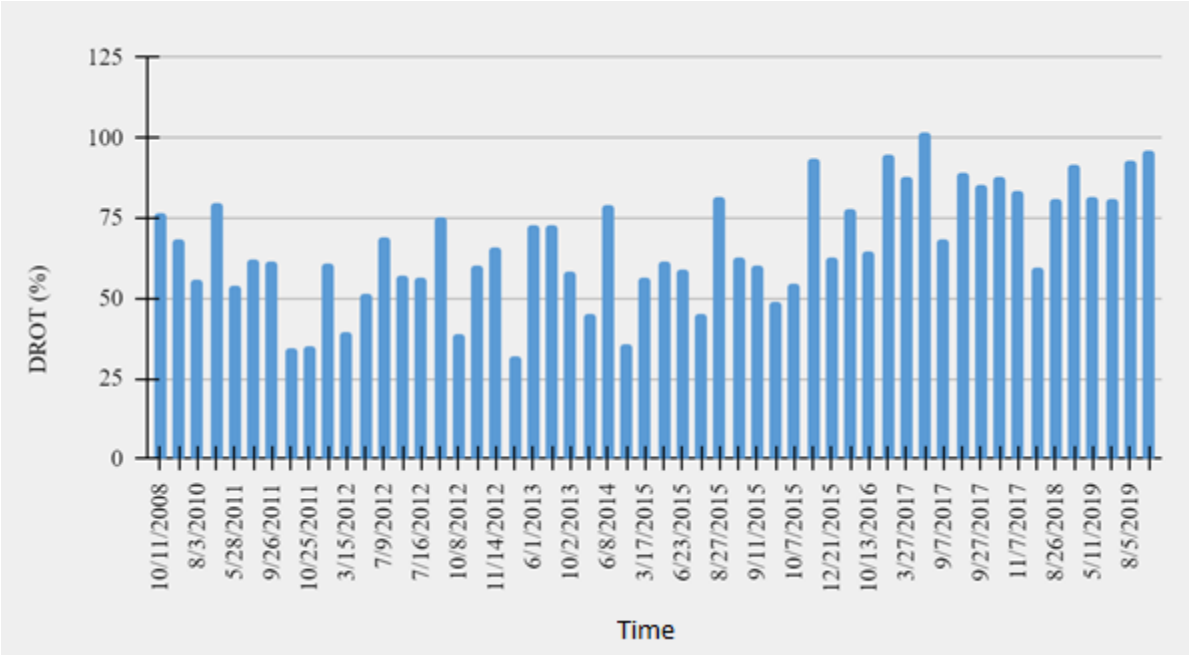

Figure 2. Temporal variation of DROT values depicting the ionospheric response to the 54 geomagnetic storms that occurred during the 24th solar cycle.

In the literature, research regarding geomagnetic storms occurring during the 24th solar cycle has indicated the presence of ionospheric responses. A study by Song, Ding et al. (2013) investigated the response of the Chinese ionosphere to a moderate geomagnetic storm on 28 May 2011, and stated that large-scale traveling ionospheric disturbances occurred in the Chinese ionosphere [35]. Another study by Berényi, Heilig et al. (2023) examining the ionospheric response to geomagnetic storms on November 14, 2012, and March 17, 2015, found a significant decrease in the critical frequency of the F region (foF2) and the total electron content (TEC) [36]. In another study by Mansilla (2018), a global response to the geomagnetic storm on 22 June 2015 was investigated, revealing both increases and decreases in ionospheric TEC values globally [37]. Many other studies have indicated various disturbances in the ionosphere due to geomagnetic storms [8, 38-43].

Furthermore, the occurrence of traveling ionospheric disturbances during geomagnetic storms has been expressed in the literature. Cherniak and Zakharenkova (2018) stated the occurrence of large-scale ionospheric disturbances during a geomagnetic storm on December 19-21, 2015 [44]. The DROT values obtained for the same storm on December 20, 2015 (93,76) in this study match the previous study. In another study by Kishore and Kumar (2023), it was mentioned that large-scale ionospheric disturbances occurred during geomagnetic storms on March 17, 2015, and June 23, 2015 [15]. However, in this study, it can be noted that medium-scale traveling ionospheric disturbances occurred during both storms. Zhang, Nishimura et al. (2022) indicated the occurrence of medium-scale traveling ionospheric disturbances during geomagnetic storms on August 25, 2018, September 7-8, 2017, and May 28, 2017, over the American continent [17]. The results obtained with the DROT method during the same storm periods in this study indicate the occurrence of large-scale traveling ionospheric disturbances over the Turkish ionosphere, except for the storm on September 7, 2017 (DROT=68,45).

3.1. Evaluation of the DROT Method

The DROT method has been defined as a technique proposed by Efendi and Arikan (2017) and used by the authors to automatically detect ionospheric disturbances and scale the intensity of these disturbances for further research [27]. This method has been employed in various studies to attempt to detect ionospheric disturbances [19, 27, 45]. Among these, Karatay (2020) attempted to classify ionospheric disturbances by applying this method to vertical TEC (V-TEC) values. In this study, the same method has been used to detect ionospheric responses to geomagnetic storms.

As expressed in the results section above, it was found that during certain geomagnetic storms, no ionospheric disturbance occurred over the Turkish ionosphere using this method. In particular, the absence of any ionospheric disturbance during severe geomagnetic storms (Dst < -100 nT) casts somewhat doubt on the results of this method. However, during the geomagnetic storm on 17.03.2013, ionospheric responses were investigated for the stations svtl (60,53 D, 29,78 K) and zamb (15,43 D, -28,31 G), located almost in the same longitude, and

medium-scale traveling ionospheric disturbances were found to occur with DROT values of 59.80% and 54.95%, respectively. Furthermore, during the same storm, DROT values were calculated for two different stations in Turkey, and for these two stations, DROT values were obtained as ankr (33.20%) and ista (35.80%). These results suggest that, while no disturbance was detected in the Turkish ionosphere according to the DROT method, medium-scale ionospheric disturbances may have occurred in other regions. Karatay (2020) stated in their study that the ability of the DROT method to detect disturbances depends on the magnitude, frequency, and duration of the data. To clearly express the ionospheric response to different forces, Karatay (2020) examined the amplitude and frequency variations of synthetic data. As a result, moderate-scale ionospheric disturbances were predicted to occur when the amplitude of these data ranges between 1.5 A0 and 2A0 and the frequency is low, while large-scale ionospheric disturbances occur when the amplitude exceeds 2.5 A0 and the frequency is lower. Here, A0=1.08 TECU. This analysis may explain why the Turkish ionosphere did not respond to some severe geomagnetic storms in this study, as the amplitude variation of the data may not have reached a sufficient magnitude. In this sense, the inability to obtain ionospheric responses during certain storms in this study could be attributed to the data not reaching a sufficient magnitude of change. It can be suggested that the DROT method may be suitable for detecting ionospheric disturbances that reach sufficient amplitude due to parameters such as geomagnetic storms, solar events, the Earth's magnetic field, and cosmic events. In the future, if this method can be integrated into ionospheric research tools, it may also be useful for detecting possible disturbances that may occur in the radio wave propagation in the ionosphere. As a result, although this method can be used for processing data above a certain magnitude, it may not be appropriate for use below a certain magnitude threshold.

4. CONCLUSION

The response of the Turkish ionosphere to 54 geomagnetic storms of varying scales during the 24th solar cycle was investigated using the DROT method applied to IONOLAB-TEC values. The research revealed that medium- and large-scale ionospheric disturbances occurred in the Turkish ionosphere during these 54 geomagnetic storms. The results obtained are consistent with those reported in the literature for some storms, while they are not consistent for others. In general, large-scale TIDs are expected to occur during severe geomagnetic storms, according to the literature. However, in this study, it was found that medium-scale disturbances occurred during some severe geomagnetic storms using the DROT method, while large-scale TIDs occurred during some moderate and low intensity geomagnetic storms. This discrepancy with the literature may arise from the fact that the ionospheric response to geomagnetic storms depends on various parameters, including latitude and longitude. Furthermore, these results highlight the importance of knowing the fundamental properties of the data, such as frequency and magnitude, for detecting ionospheric disturbances using the DROT method. Examining TIDs in the ionosphere contributes to our understanding of the dynamic and complex nature of the upper atmosphere of Earth. This information is crucial to improving ionospheric models, enhancing space weather forecasts, and developing strategies to mitigate the impact of ionospheric disturbances on various technological systems.

ACKNOWLEDGEMENTS

The author would like to thank the IONOLAB group for the opportunities they provided in obtaining TEC data and OMNIWEB for the opportunities they provided in obtaining geomagnetic parameters.

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MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

Bazı N-Sübstitüe Ftalimid Türevlerinin Antimikrobiyal Etkilerinin İncelenmesi

Investigation of Antimicrobial Effects of Some N-Substituted Phthalimide Derivatives

Sefa ISIK[1], Ayse TAN[2]

[1,2] *Vocational School of Technical Sciences, Mus Alparslan University, Muş, TÜRKİYE*
s.isik@alparslan.edu.tr —ORCİD 0000-0002-1480-7230
a.tan@alparslan.edu.tr —ORCİD 0000-0003-2692-7923

Makale Bilgisi / Article Information

Makale Türü / Article Types	Araştırma Makalesi / Research Article
Alınış Tarihi / Received	31 Temmuz / July 2024
Kabul Tarihi / Accepted	07 Ekim / October 2024

Yıl / Year: 2024 | **Cilt / Volume:** 1 | **Sayı / Issue:** 2 | **Sayfa / Pages:** 57-61

Atıf Formatı / Cite as: Isık, S., Tan, A., "Bazı N-Sübstitüe Ftalimid Türevlerinin Antimikrobiyal Etkilerinin İncelenmesi", Hendese, Vol. 1, Issue 2, Pages 57-61, 2024.

Sorumlu Yazar / Corresponding Author: Ayse TAN

https://doi.org/10.5281/zenodo.13996463

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
ARAŞTIRMA MAKALESİ

Bazı *N*-Sübstitüe Ftalimid Türevlerinin Antimikrobiyal Etkilerinin İncelenmesi

Sefa ISIK[1], **Ayse TAN**[*2]

[*1,2]*Vocational School of Technical Sciences, Mus Alparslan University, Muş, TÜRKİYE*

(**Alınış / Received:** 31.07.2024, **Kabul / Accepted:** 07.10.2024, **Online Yayınlanma / Published Online:** 27.10.2024)

Anahtar Kelimeler
Ftalimid,
Antimikrobiyal,
Antibakteriyel,
Antifungal,
Dietilamin

ÖZ

Bu çalışmada, bazı *N*-sübstitüe ftalimid türevlerinin (**2**, **3**, **4a-c**) antimikrobiyal etkileri Gram-negatif (jenerik *Escherichia coli*, *Salmonella enterica* Typhimurium, *Citrobacter freundii, Klebsiella pneumoniae,* şiga toksin üreten *E. coli* O157:H7 (STEC O157:H7)) ve Gram-pozitif bakteriler (*Stapylococcus aureus*, *Listeria monocytogenes*) üzerinde incelenmiştir. *N*-sübstitüe ftalimid türevlerinin antifungal etkileri ise maya (*Candida albicans*) ve küf (*Aspergillus brasiliensis*) üzerinde test edilmiştir. Antimikrobiyal analizlerde bakterilere karşı vankomisin-30 µg (VA-30), rifampisin-5 µg (RA-5) ve tetrasiklin-30 µg (TE-30), funguslara karşı ise karşı flukonazol-25 µg (FZ-25) pozitif kontrol grubu olarak kullanılmıştır. Genel olarak, *N*-sübstitüe ftalimid türevlerinin (**2**, **3**, **4a-c**) Gram-negatif, Gram-pozitif bakteriler, maya ve küf üzerinde önemli antimikrobiyal aktivitelere sahip olduğu gözlemlenmiştir. Yapısında dietilamin grubu ihtiva eden **4c** bileşiği *C. freundii* ve *L. monocytogenes* üzerinde diğer ftalimid türevlerine ve kontrol bileşiklerine göre en iyi aktiviteyi göstermiştir. Diğer taraftan Br içeren **3** bileşiğinin, *C. freundii* hariç hem antibakteriyel hem de antifungal etkisi ile geniş spektrumlu antimikrobiyal özelliklere sahip olduğu görülmüştür. Sonuç olarak, *N*-sübstitüe ftalimid türevleri (**2**, **3**, **4a-c**) yeni ümit verici antimikrobiyal ajanlar olarak düşünülebilir.

Investigation of Antimicrobial Effects of Some *N*-Substituted Phthalimide Derivatives

Keywords
Phthalimide,
Antimicrobial,
Antibacterial,
Antifungal,
Diethylamine

ABSTRACT

In this study, antimicrobial effects of some *N*-substituted phthalimide derivatives (**2**, **3**, **4a-c**) were investigated on Gram-negative (generic *Escherichia coli*, *Salmonella enterica* Typhimurium, *Citrobacter freundii*, *Klebsiella pneumoniae*, shiga toxin producing *E. coli* O157:H7 (STEC O157:H7)) and Gram-positive bacteria (*Stapylococcus aureus*, *Listeria monocytogenes*). The antifungal effects of *N*-substituted phthalimide derivatives were tested on yeast (*Candida albicans*) and mold (*Aspergillus brasiliensis*). In the antimicrobial analysis, vancomycin-30 µg (VA-30), rifampicin-5 µg (RA-5) and tetracycline-30 µg (TE-30) against bacteria and fluconazole-25 µg (FZ-25) against fungi were used as positive control groups. In general, *N*-substituted phthalimide derivatives (**2**, **3**, **4a-c**) have been observed to have important antimicrobial activities on Gram-negative, Gram-positive bacteria, yeast, and mold. Compound **4c**, which contains a diethylamine group in its structure, showed the best activity on *C. freundii* and *L. monocytogenes* compared to other phthalimide derivatives and control compounds. On the other hand, compound **3** containing Br has been observed to have broad-spectrum antimicrobial properties with both antibacterial and antifungal effects, except for *C. freundii.* In conclusion, *N*-substituted phthalimide derivatives (**2**, **3**, **4a-c**) can be considered new promising antimicrobial agents.

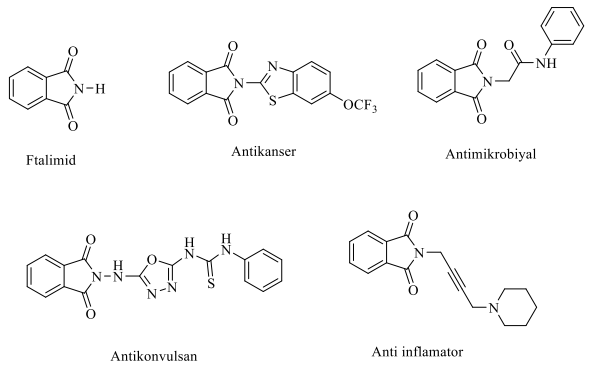
Corresponding Author: a.tan@alparslan.edu.tr
Cilt / Volume: 1 **Sayı / Issue:** 2

Atıf Formatı / Cite as: Isık, S., Tan, A., "Bazı N-Sübstitüe Ftalimid Türevlerinin Antimikrobiyal Etkilerinin İncelenmesi", Hendese, Vol. 1, Issue 2, Pages 57-61, 2024.

Doi: 10.5281/zenodo.13996463

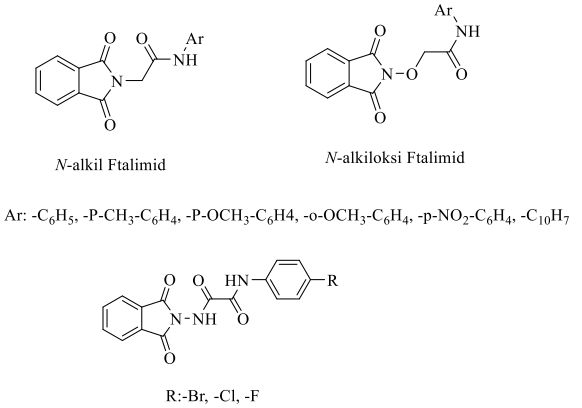
1. GİRİŞ

Ftalimid türevi bileşikler, biyolojik olarak aktif olmalarına yardımcı olan bir imid halkasına (–CO-N(R)-CO-) sahiptir, bu nedenle farmasötik açıdan oldukça faydalı bileşiklerdir [1]. İzoindolin-1,3-dion olarak da bilinen ftalimid ve onun *N*-sübstitüe türevleri, organik kimyada çok çeşitli biyolojik aktivitelere sahip önemli bir bileşik sınıfını oluşturmaktadır. Ftalimid türevlerinin antikanser, antikolinesteraz, antimikrobiyal, antifungal, anti-inflamatuar, VEGFR-2 inhibitörü, antioksidan, antiviral ve antikonvülsan gibi etkilere sahip olduğu bilinmektedir [2-15] (Şekil 1).



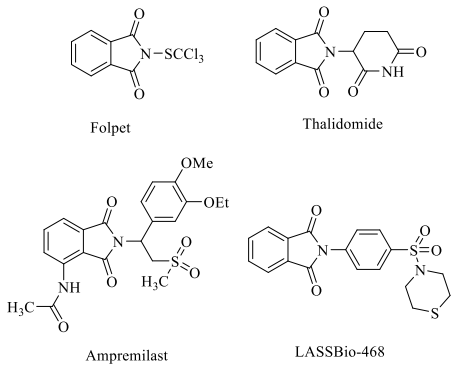
Şekil 1. Bazı biyoaktif ftalimid türevleri.

N-sübstitüe ftalimid türevlerinin antibikrobiyal etki gösterdiği pek çok çalışmada rapor edilmiştir. Pawar ve grubu ftalimitin çeşitli *N*-alkil ve *N*-alkiloksi türevlerini sentezlemiş ve oldukça güçlü antifungal etki gösterdiğini rapor etmiştir [3] (Şekil 2). Baluja ve grubunun yapmış olduğu bir çalışmada, 2-hidrazinil-2-okso-*N*-fenilasetamid ve ftalik anhidritin kondenzasyonu ile çeşitli *N*-sübstitüe ftalimid türevi bileşiklerin sentezi gerçekleştirilmiş. Sentezlenen tüm bileşiklerin *N*,*N*-dimetil formamid ve dimetil sülfoksitte çeşitli bakteri ve mantar türlerine karşı antimikrobiyal etkileri *in vitro* çalışmalarla test edilmiştir. Elde edilen sonuçlara göre, bileşiklerin büyük bir kısmının orta derecede antimikrobiyal aktivite gösterdiği ve antimikrobiyal çalışmalarda *N*,*N*-dimetil formamitin, dimetil sülfoksitten daha iyi bir çözücü olduğu rapor edilmiştir [14] (Şekil 2).



Şekil 2. Bazı antimikrobiyal ftalimid türevleri [3,14].

Ayrıca ticari olarak satılan bazı ftalimid türevi ilaçlar da vardır. Folpet, mantar ilacı olarak kullanılan bir bileşiktir. Talidomid, antineoplastik ve antileprotik özellikleri ile bilinirken, ampremilast astım ve akciğer hastalıklarının tedavisinde kullanılan bir fosfodiesteraz-4 inhibitörüdür. Lassbio-468 ise bir fosfodiesteraz-4 inhibitörü olup, anti-inflamatuar etkileri sayesinde romatoid artrit ve şok septik sendromu tedavisinde kullanılmaktadır. [1] (Şekil 3).

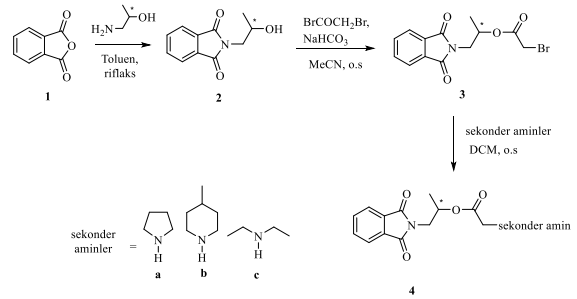


Şekil 3. Bazı ftalimid türevi ticari ilaçlar.

2. MATERYAL VE METOT

2.1. Sentez

Daha önce yaptığımız bir çalışmada, bazı *N*-sübstitüe ftalimid türevlerinin (**2**, **3**, **4a-c**) sentezi, karakterizasyonu ve bunların antikolinesteraz inhibitör özellikleri rapor edilmiştir [5]. Sentezlenen tüm bileşiklerin oldukça güçlü kolinesteraz inhibitörü oldukları, özellikle de **4b** bileşiğinin en iyi aktivite gösterdiği bildirilmiştir. Aynı zamanda, *in silico* çalışmalar ile, bileşiklerin enzim ile etkileşim mekanizması ve ADME çalışmaları ile ilaç benzerlikleri incelenmiştir. Buna göre ilgili bileşiklerin, enzimlerin aktif bölgeleri ile iyi etkileşim yaptıkları ve ADME çalışmalarına göre de düşük toksisite ve kabul edilebilir ilaç benzerlik skorlarına sahip oldukları bildirilmiştir. Mevcut çalışmamızda bu bileşikler literatürde belirtildiği şekilde yeniden sentezlendi [5]. Öncelikle, ftalik anhidritin (**1**) DL-1-amino-2-propanol ile toluen içerisinde reaksiyonundan ftalimid türevi **2** bileşiği sentezlendi. **2** bileşiğinin asetonitril (MeCN) içerisinde $NaHCO_3$ varlığında bromoasetil bromür ($BrCOCH_2Br$) ile reaksiyonundan bileşik **3** elde edildi. **3** bileşiğinin, diklorometan (DCM) içerisinde çeşitli ikincil aminler (sırasıyla pirolidin, 4-metil piperidin ve dietilamin) ile oda sıcaklığında reaksiyonu gerçekleştirilerek hedef bileşikler (**4a-c**) sentezlendi (Şekil 4). Sentez basamakları Şekil 4'te özetlenmiştir [5].



Şekil 4. *N*-sübstitüe ftalimid türevlerinin (**2**, **3**, **4a-c**) sentez basamakları.

2.2. Antimikrobiyal Aktivite

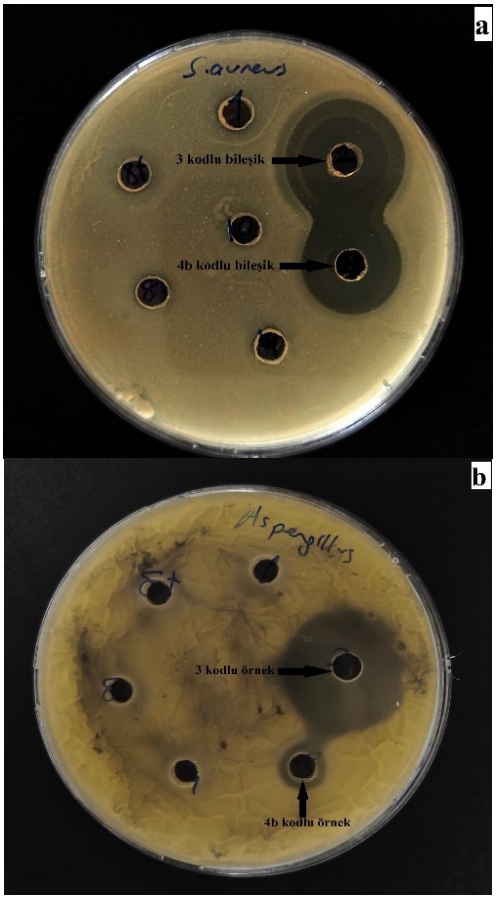
Antibakteriyel aktivitenin belirlenmesinde test mikroorganizması olarak jenerik *Escherichia coli* (ATCC 25922), *Stapylococcus aureus* (ATCC 25923), *Listeria monocytogenes* (ATCC 7644), *Salmonella enterica* Typhimurium (ATCC 14028), *Citrobacter freundii* (ATCC 43864), *Klebsiella pneumoniae* (ATCC 13883) ve şiga toksin üreten *E. coli* O157:H7 (STEC O157:H7) (ATCC 35150) kullanılmıştır. Antifungal aktivitenin tespiti için ise *Candida albicans* (ATCC 10231) ve *Aspergillus brasiliensis* (ATCC 16404) kullanılmıştır. Kültürler Muş Alparslan Üniversitesi Moleküler Biyoloji ve Genetik Bölümü Laboratuvarı'ndan temin edilmiştir. Bakterilerin gelişim ortamı olarak Tryptic Soy Agar (TSA, Biolife; İtalya), ve Tryptic Soy Broth (TSB, Merck KGaA, Almanya), *C. albicans* ve *A. brasiliensis* için ise Sabouraud Dextrose Agar (SDA; Oxoid, USA) ve Sabouraud Dextrose Broth (Difco Laboratories, USA) kullanılmıştır.

Ftalimid türevlerinin (**2**, **3** ve **4a-c)** antimikrobiyal aktivitelerinin ölçülmesi amacıyla, dimetilsülfoksit çözücüsü (Dimethylsulfoxide (DMSO), Anhydrous, 99.9%, Sigma Aldrich) kullanılarak 2048 ppm konsantrasyona sahip bileşiklerin çözeltileri hazırlanmıştır. Ardından çözeltiler 0.22 µm por çapına sahip steril filtreden geçirilerek steril tüplere aktarılmıştır. Steril fizyolojik tuzlu su kullanılarak McFarland 0.5 standardına ayarlanmış (10^8 kob/mL) süspansiyonlar hazırlanmıştır. Bakteri ve fungus süspansiyonlarından sırasıyla TSA ve SDA içeren petrilere 100 µL süspansiyondan inoküle edilerek steril drigalski ile yüzey kaplanmıştır. Antimikrobiyal aktivitenin tespiti agar kuyu difüzyon yöntemine göre gerçekleştirilmiştir [15, 16]. Etken maddelerin ilavesi için agar yüzeyinde 6 mm kuyucuklar açılmıştır. Kuyucuklara etken maddeden 100 µL ilave edilmiştir [17]. Bakteri inoküle edilmiş petri kapları 37 °C'de 24 saat, maya içeren petriler 28 °C'de 48 saat ve küf içeren petriler 28 °C'de 72-96 saat inkübasyona bırakılmıştır [18]. Bakteriler için vankomisin-30 µg (VA-30), rifampisin-5 µg (RA-5), tetrasiklin-30 µg (TE-30), funguslara karşı ise flukonazol-25 µg (FZ-25) pozitif kontrol olarak kullanılmıştır. Dimetilsülfoksit ise negatif kontrol grubu olarak kullanılmıştır. İnkübasyon süresinin sonunda, ftalimid türevi bileşiklerin antimikrobiyal aktivitesini değerlendirmek için kuyucukların etrafında oluşan inhibisyon zonları dijital kumpas kullanılarak ölçülmüştür. Araştırma paralel olarak yürütülmüştür.

3. DENEYSEL BULGULAR

3.1. Antimikrobiyal aktivite

Bu çalışmada sentezlenen bileşiklerin antimikrobiyal aktiviteleri, bakteriler (Gram-negatif ve Gram-pozitif), maya ve küfe karşı incelenmiştir. Elde edilen veriler Çizelge 1 ve 2'de özetlenmiştir. Genel olarak, bileşiklerin Gram-negatif ve Gram-pozitif bakterilere, maya ve küf üzerine değişen derecelerde antimikrobiyal aktivitelere sahip olduğu gözlemlenmiştir. Bileşik **3**'ün, *C. freundii* hariç hem antibakteriyel hem de antifungal etkisi ile geniş spektrumlu antimikrobiyal özelliklere sahip olduğu görülmüştür. Bileşik **3**, *S. aureus*'a (25.95 ± 0.34 mm) (Şekil 5a) ve *A. brasiliensis*'e (31.91 ± 0.39 mm) (Şekil 5b) karşı yüksek antimikrobiyal aktivite sergilemiştir. **4a** bileşiği, test edilen gruplar arasında ikinci en yüksek antibakteriyel etkiye sahip olduğu bununla birlikte *C. albicans* üzerinde en yüksek antifungal etkiyi gösterdiği belirlenmiştir. **4c** bileşiği, genel olarak *S. aureus* hariç düşük seviyelerde geniş spektrumlu bir aktivite göstermiştir.



Şekil 5. *N*-sübstitüe ftalimid türevlerinin *S. aureus* (a) ve *A. brasiliensis'*e karşı antimikrobiyal aktivite görüntüleri.

Gram negatif bakteriler incelendiğinde jenerik *E. coli* üzerine **3**, **4b** ve **4c** numaralı bileşiklerin antimikrobiyal özelliğe sahip olduğu görülmüştür. En yüksek inhibisyon zonu **4b** numaralı bileşikte (10.03 ± 0.04 mm) tespit edilmiştir. *S.* Typhimurium üzerine sadece **3**, **4a** ve **4c** numaralı bileşikler antimikrobiyal aktivite sergilerken, diğer örneklerde zon oluşumu tespit edilmemiştir. En yüksek inhibisyon bileşik **3**'te (13.95 ± 0.57 mm) tespit edilmiştir. *C. freundii*, etken maddelere karşı en dirençli bakteri olarak öne çıkmıştır. Bileşiklerden sadece **4c** (8.83 ± 0.17 mm) antimikrobiyal aktivite göstermiştir. *K. pneumoniae*'ye karşı tüm bileşikler sınırlı da olsa 9.05-9.96 mm arasında değişen zon oluşturmuşlardır. *K. pneumoniae* ile benzer şekilde bileşiklerin hepsi STEC O157:H7 üzerinde de antimikrobiyal etki göstermiştir. En yüksek etki, bileşik **3** (14.23 ± 0.16 mm), en düşük etki ise bileşik **2** de (8.96 ± 1.96 mm) tespit edilmiştir. Gram pozitif bakterilerden *S. aureus* üzerinde en yüksek bakteriyel inhibisyon zonları, **3** ve **4a** bileşikleri için sırasıyla 25.95 ± 0.34 mm ve 21.45 ± 0.62 mm olarak tespit edilmiştir.

Çizelge 1. *N*-sübstitüe ftalimid türevleri (**2**, **3**, **4a-c**) (2048 ppm) ve referans bileşiklerinin antibakteriyel aktiviteleri.

Antibakteriyel Aktivite (İnhibisyon zon bölgesi (mm))							
Bileşikler	**Gram (-)**					**Gram (+)**	
	Jenerik *E. coli*	***S.* Typhimurium**	***C. freundii***	***K. pneumoniane***	**STEC O157:H7**	***S. aureus***	***L. monocytogenes***
2	-	-	-	9.48 ± 0.89	8.96 ± 1.96	-	-
3	9.42 ± 1.48	13.95 ± 0.57	-	9.41 ± 0.64	14.23 ± 0.16	25.95 ± 0.34	8.35 ± 1.43
4a	-	12.0 ± 0.96	-	9.05 ± 0.52	13.8 ± 0.71	21.45 ± 0.62	-
4b	10.03 ± 0.04	-	-	9.96 ± 0.51	11.23 ± 1.60	-	-
4c	9.34 ± 0.04	11.41 ± 1.98	8.83 ± 0.17	9.06 ± 0.48	9.31 ± 0.20	-	9.71 ± 1.10
VA-30	7.62 ± 0.79	-	-	-	9.99 ± 1.43	16.64 ± 1.14	-
RA-5	-	-	-	-	-	25.05 ± 1.26	-
TE-30	16.2 ± 1.72	15.39 ± 0.00	-	16.51 ± 1.16	16.51 ± 1.98	22.95 ± 0.96	-

Kısaltmalar: **VA-30**: Vankomisin-30 µg; **RA-5**: Rifampisin-5 µg; **TE-30**: Tetrasiklin-30 µg

3.2. Yapı-Aktivite İlişkisi

Antimikrobiyal aktivitesi incelenen *N*-sübstitüe-ftalimid türevleri (**2**, **3**, **4a-c**) yapısal olarak bir benzen halkası ve buna kondanse 5 üyeli bir imit halkasına sahiptir. Bileşiklerdeki yapısal farklılık ise imit halkasındaki N atomuna bağlı gruplardır. Bu anlamda bileşiklerin antimikrobiyal aktivitelerinin değişkenliğine N atomuna bağlı grupların etki ettiğini söylemek mümkündür. **2** bileşiği yapısında OH grubu bulundururken, **3** bileşiği $OCOCH_2Br$ grubunu içermektedir. Diğer taraftan **4a-c** bileşiklerindeki yapısal farklılığı ise $OCOCH_2$-sekonder amin şeklinde ifade edebiliriz. Buradaki sekonder amin grupları **4a**, **4b**, ve **4c** bileşikleri için sırasıyla pirolidin, 4-metilpiperidin ve dietilamindir.

Jenerik *E. coli* üzerindeki antibakteriyel aktivitede, ftalimid türevleri arasında yapısında OH grubu bulunduran bileşik **2** ve $OCOCH_2$-pirolidin bulunduran **4a** hariç diğer bileşiklerin (**3**, **4b** ve **4c)** antibakteriyel aktivite gösterdiği tespit edilmiştir. **4b** ve **4c** bileşikleri içinde 4-metilpiperidin halkası bulunduran **4b** bileşiğinin dietilamin içeren **4c** bileşiğine göre daha iyi aktivite sergilediği görülmektedir. 4-metilpiperidin halkasının jenerik *E. coli* üzerine antibakteriyel aktivitede etkili olduğu düşünülmektedir.

Çizelge 2. *N*-sübstitüe ftalimid türevleri (**2**, **3**, **4a-c**) (2048 ppm) ve referans bileşiklerinin antifungal aktiviteleri

Bileşikler	Antifungal Aktivite (İnhibisyon zon bölgesi (mm))	
	Maya	**Küf**
	C. albicans	***A. brasiliensis***
2	10.27 ± 0.18	-
3	10.47 ± 1.11	31.91 ± 0.39
4a	15.15 ± 0.12	9.42 ± 1.99
4b	7.82 ± 1.42	-
4c	10.22 ± 0.72	-
FZ-25	17.35 ± 2.25	15.04 ± 0.44

Kısaltmalar: FZ-25: Flukonazol-25 µg

S. Typhimurium üzerinde **2** ve **4b** bileşiklerinin aktivite göstermediği, buna karşın **3, 4a** ve **4b** bileşiklerinin iyi bir antibakteriyel aktivite sergilediği tespit edilmiştir. Bu bileşiklerin yapısına bakıldığında, Br grubunu içeren **3** bileşiğinin en iyi aktiviteyi göstermesi, *S.* Typhimurium üzerinde Br grubunun etkili olabileceğini göstermektedir.

C. freundii üzerinde sadece dietilamin grubu içeren **4c** bileşiği aktivite gösterirken, diğer bileşiklerde anlamlı bir aktivite izlenmemiştir. Bu durum, *C. freundii* üzerinde dietilamin grubunun aktivitede etkin rol oynadığını göstermektedir. Referans bileşikleri VA-30, RA-5 ve TE-30'un *C. freundii* üzerinde etkili olmamasına karşın, **3** bileşiğinin antibakteriyel etki göstermesi önem taşımaktadır.

K. pneumoniae üzerine antibakteriyel aktivite incelendiğinde, referans bileşikler VA-30 ve RA-5 herhangi bir etki göstermezken, tüm ftalimid bileşikleri **(2, 3, 4a-c)** anlamlı ve benzer bir etki göstermiştir.

STEC O157:H7 üzerine antibakteriyel aktivitede, tüm ftalimid bileşiklerinin anlamlı bir etki gösterdiği gözlemlenmiştir. Yapısında Br bulunan **3** bileşiği, en yüksek aktiviteyi sergilerken, pirolidin içeren **4a** bileşiği de ona göre biraz daha düşük olmakla birlikte yüksek bir aktivite göstermiştir. Bu bileşiklerin aktivitelerinin diğerlerine göre daha iyi olduğu dikkat çekmektedir. STEC O157:H7 üzerinde Br ve pirolidin gruplarının aktivitede önemli rol oynadığı düşünülmektedir.

S. aureus üzerinde yapılan antibakteriyel çalışmada ise, **2**, **4b**, ve **4c** bileşikleri herhangi bir etki göstermezken, yapısında Br olan **3** bileşiğinin aktivitesinin hem referans bileşiklerinden hemde diğer ftalimid türevlerinden daha iyi olduğu tespit edilmiştir. Bu durumda *S. aureus* üzerindeki aktivitede özellikle Br ve pirolidin gruplarının etkin rol oynadıkları düşünülmektedir.

L. monocytogenes üzerinde yapılan aktivite çalışmasında yine Br içeren **3** bileşiğinin ve dietilamin içeren **4c** bileşiğinin belirgin bir aktivite gösterdiği tespit edilmiştir. Bu durumda *L. monocytogenes* üzerinde Br ve dietilamin gruplarının etkin rol oynadıkları düşünülmektedir.

Yapmış olduğumuz antifungal aktivite çalışmasında, *C. albicans* üzerinde bütün bileşiklerin bir aktivite gösterdiği

görülmüştür. *A. brasiliensis* üzerine yapısında Br bulunduran **3**, ve pirolidin bulunduran **4a** bileşikleri yüksek antifungal aktivite gösterirken, diğer ftalimid türevleri herhangi bir etki göstermemiştir. Bu durumda yine Br grubunun *A. brasiliensis* üzerine antifungal aktivitede etkili olduğu görülmektedir. Yapı-aktivite ilişkisinde, genel olarak, Br ve dietil amin gruplarının antimikrobiyal aktivitede etkin rol oynadığı düşünülmektedir.

4. SONUÇLAR

Bu çalışmada, bazı *N*-sübstitüe ftalimid türevlerinin (**2**, **3**, **4a-c**) sentezi ve antimikrobiyal etkileri incelenmiştir. Ftalimid türevlerinin antibakteriyel aktiviteleri Gram-negatif ve Gram-pozitif bakteriler üzerinde test edilmiştir. Antifungal etkileri ise maya ve küf üzerinde test edilmiştir. Antibakteriyel analizlerde VA-30, RA-5 ve TE-30, funguslara karşı ise FZ-25 pozitif kontrol grubu olarak kullanılmıştır. Genel olarak, *N*-sübstitüe ftalimid türevlerinin (**2**, **3**, **4a-c**) önemli ölçüde antimikrobiyal aktivitelere sahip olduğu gözlemlenmiştir. Özellikle **4c** bileşiği, *C. freundii* ve *L. monocytogenes* üzerinde hem diğer ftalimid türevlerine hemde kontrol bileşiklerine göre en iyi aktiviteyi göstermiştir. Diğer taraftan, yapısında Br bulunduran **3** bileşiğinin, *C. freundii* hariç hem antibakteriyel hem de antifungal etkisi ile geniş spektrumlu antimikrobiyal özelliklere sahip olduğu tespit edilmiştir. Elde edilen sonuçlara göre, genel olarak ilgili ftalimid türevleri (özellikle **3** ve **4c**) umut vadeden aktiviteleri nedeniyle potansiyel olarak etkili yeni antimikrobiyal ajanlar olarak düşünülebilir.

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Yazarlar Muş Alparslan Üniversitesi'ne teşekkür eder.

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HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

Investigation of Microstructure and Mechanical Properties (Ni-Cr-Mo) Dental Prosthesis

Ebuzer AYGUL [1]

[1] *Vocational School of Health Services, Hakkari University, Hakkari, TÜRKİYE*
ebuzeraygul@hakkari.edu.tr—ORCID 0000-0003-0930-3975

Article Information

Article Types	Research Article
Received	07 March 2024
Accepted	11 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 62-66

Cite as: Aygul, E., "Investigation of microstructure and mechanical properties (Ni-Cr-Mo) dental prosthesis", Hendese, Vol. 1, Issue 2, Pages 62-66, 2024.

Corresponding Author: Ebuzer AYGUL

https://doi.org/10.5281/zenodo.13996483

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
RESEARCH ARTICLE

Investigation of Microstructure and Mechanical Properties (Ni-Cr-Mo) Dental Prosthesis

Ebuzer AYGUL[*1]

[*1] *Vocational School of Health Services, Hakkari University, Hakkari, TÜRKİYE*

(**Received:** 07.03.2024, **Accepted:** 11.10.2024, **Published Online:** 27.10.2024)

Keywords
Dental prosthesis,
Microstructure,
Ni-Cr-Mo.

ABSTRACT

Ni63.4-Cr23.6-Si1.4-Mo11 metal ceramic (CERMET) dental alloy is widely used in dentistry applications instead of expensive alloys. The biocompatibility of the Ni63.4-Cr23.6-Si1.4-Mo11 alloy may pose a problem due to the metals present in the alloy as a result of corrosion activity, so examining its microstructure and mechanical properties is quite important. 11mm diameter Ni63,4-Cr23,6-Si1,4-Mo11 alloy disc was produced using the standard casting method for analyzing. Scanning Electron Microscope (SEM), X-ray Diffraction (XRD), Energy Dispersive X-ray Spectroscopy (EDX), Electrochemical Corrosion (Tafel extrapolation) and Micro Hardness test methods were used to examine the microstructure and mechanical properties of the alloy produced. According to the findings obtained from the results, the corrosion rate of the sample was measured as (940,3 x 10-3mpy) and the average Vickers hardness value was (366,54 kg x mm-2). It was seen that the alloy was in dendritic structure from SEM analysis, and Ni dominant XRD phase was detected in XRD tester. It was seen in SEM mapping that all the elements used in the alloy showed a homogeneous structure.

Corresponding Author: ebuzeraygul@hakkari.edu.tr
Volume: 1 **Issue:** 2

Cite as: Aygul, E., "Investigation of microstructure and mechanical properties (Ni-Cr-Mo) dental prosthesis", Hendese, Vol. 1, Issue 2, Pages 62-66, 2024.

Doi: 10.5281/zenodo.13996483

1. INTRODUCTION

The use of metal alloys in dental prostheses is associated with good mechanical properties, biocompatibility, high corrosion immunity and good casting properties. The most popular dental alloys are nickel, titanium and cobalt [1,2] based alloys, where permanent prostheses-bridges, crowns and implants covered with polymer, composite or ceramic are realized [3,4].

Recently, Nickel-Chromium-Molybdenum (Ni-Cr-Mo) based alloys have begun to be widely used instead of expensive precious metal alloys used in dental applications. The use of Ni-Cr-Mo based alloys in dentistry is increasing, especially in the production of fixed dental prostheses [5]. Although there are doubts about the biocompatibility of this alloy (Ni-Cr-Mo), is still chosen as the base metal because of its higher elastic modulus than the noble, offering the advantage of retaining hardness with less bulk. The electrochemical corrosion behavior of Ni-Cr-Mo metal ceramic dental alloy primarily in tandem the Cr and Mo grades in an alloy [6]. Chromium is the basis alloying element in Ni-base alloys and is added to support the consist of a decisive passive oxide layer that is quite corrosion resistant. Molybdenum is often added to increase corrosion immunity [7].

The chemical composition of Ni-Cr-Mo casting alloys mainly comprise of 65-80% Ni and 8-22% Cr as well as Mo 3.8or4%, W 4% or (more rarely) Be, Si [8]. Total Ni + Cr + Mo content should be equal to a minimum of 85% by weight. A direct correlation has been established between cast alloy structures and polarization immunity behavior [8]. Although casting of Ni-Cr-Mo metal ceramic dental alloy is difficult, it is still the traditional method of preparing the metal substrate for economic concerns, due to its high melting range and oxidation potential during casting [9].

With the development of dental technology, many attentions have focused on methods of appropriately fabricating Ni-Cr-Mo dental alloy and facilitating the finishing process [10]. Biocompatibility of the material in biomaterials, especially in alloys used in dental applications, is directly related to the corrosion properties of the material [11,12]. Biomaterials corrode with the effect of acidic and basic inhibitors in the aggressive tissue fluid occasion of the human body. Especially for dental alloys, it can be given as a cause of sudden changes in salivary fluid and food temperature in addition to tissue fluid [13]. The electrochemical corrosion test was performed for the corrosion test of Ni-Cr-Mo alloy. Ringer's solution was used for the aqueous occasion of the electrochemical corrosion test.

The hardness of the Ni-Cr-Mo metal ceramic alloy is such that it allows easy mechanical work. The micro hardness value of the alloy (Ni-Cr-Mo) was obtained with the Vickers hardness tester. After the electrochemical and mechanical tests, microstructure and surface morphology examinations of the alloy (Ni-Cr-Mo) were carried out by means of an X-ray micro analyzer and a scanning electron microscope. The purpose of the tests are to examine the behavior of a commercial Ni-Cr-Mo alloy in an organic solution by comparing its microstructural, X-ray diffraction and corrosion immunity properties.

2. MATERIALS AND METHODS

One of the test samples was the mercantile Ni63,4-Cr-23,6-Si-1,4-Mo11 metal ceramic (CERMET) dental alloy Provided by the company (MESA/ITALY- 9 mm in diameter and 12 mm high). The chemical composition of the prospect alloys is presented in Table 1. The physicochemical and mechanical properties of the Ni-Cr-Mo metal ceramic alloy declared by the producer are compiled in Table 2.

Table 1. Chemical composition of tested alloy Ni-Cr-Mo metal ceramic alloy.

Metal Ceramic Dental Alloy	Ni *(%)*	Cr *(%)*	Mo *(%)*	Si *(%)*	Rest *(%)*
Ni63,4-Cr 23,6-Si 1,4-Mo11	63,4	23,6	11	1,4	0,6

XRD analysis for Ni63,4-Cr-23,6-Si-1,4-Mo11 metal ceramic dental alloy was performed using XRD-6100 Shimadzu device. XRD measurement details are as follows; Cu X-Ray tube, Voltage = 40.0 (kV), and current = 30.0 (mA). FEI XL30 Sirion scanning electron microscope was used to determine the surface morphology of the alloy. Micro hardness values of the samples were obtained with the FM-310 Vickers hardness tester. Finally, the corrosion rates of the samples were decisive by electrochemical corrosion test.

Gamry company's interface-1000 serial electrochemical analyzer was used for corrosion measurements of the samples. Electrochemical Tafel curve analyses were obtained using Gamry Echem Analyst software. Ringer's solution was chosen for the aqueous environment of the electrochemical corrosion test as an element of the in vivo study of the alloys. To form the solution, one Ringer's tablet was calcined in 500 ml distilled water at 121 °C for 15 minutes. Typical chemical composition of the tablet used; Ammonium Chloride 0,00525; Sodium Hydrogen Carbonate 0,005; Calcium chloride-2-hydrate 0,04; potassium chloride 0,00525; sodium chloride 1,125.

Table 2. Mechanical and physical properties of Ni-Cr-Mo metal ceramic alloy according to producer

Mechanical properties		Physical properties	
Hardness (HV)	350-400	Density *(g/cm^3)*	8,3-8,4
Elasticity Mod. (Gpa)	200-230	Casting Temp. *(^0C)*	1270-1395
Tensile st. (Mpa/mm^2)	800	Sol & Liq. *(^0C)*	1309-1417

3. RESULT AND DISCUSSIONS

Figure 1 indicate the XRD pattern of Ni-Cr-Mo metal ceramic alloy with lattice parameter which related peaks degree. The lattice crystal structures obtained were found to be in concert with the available literature data (reference below and Mehta et al., 2015a, 2015b). There is an increase in the main peaks due to the presence of nickel present, but the differences in the value of the increase seen in the peaks vary depending on the content of the alloy and the atomic radius.

The atomic radius of the elements was found Ni, Cr, Mo and Si 1,62 Å, 1,85 Å, 2,01 Å and 2,1 Å respectively. In the results obtained, the dominant Ni peak in the main phase and Ni, Cr peaks respectively are remarked in figure 2 [14-16]. Figures 2a and 2b show SEM (SE) micrographs of Ni-Cr-Mo cermet dental material obtained at 800 X and 1600 X magnification. As a result of the SEM (SE) examinations, surface structure of the alloy has been revealed. The morphological structure of the alloy is typically consisting of intermetallic dendritic, as seen in existing cast materials. In pursuant of the literature (reference below and Perricone at al., Augustyn at all), in the structure of Ni-Cr-Mo metal ceramic alloy, dendrites mainly consist of intermetallic phases [8,17].

SEM mapping according to K and L energy shells of the alloy formed with Ni-Cr and Mo element additives is given in Figures 2c, 2d and 2e. The samples produced are CrK, Mo and NiK from left to right according to the energy shell mapping given. These metals generally show up as small precipitates in the SEM pictures of the alloy. The general result of the SEM mapping is that the Cr, Mo and Ni elements in the alloy have a homogeneous distribution. Measurement can be performed for this alloy to investigate how it will behave. Figure 3b shows the graphical data resulting from the Tafel analysis. It is seen that Ni-Cr-Mo metal ceramic alloy is close to show passivation feature. It is seen that the protective layer formed on its surface has a strong adhesion and reaction to the electrolytic solution. It is seen that it exhibits a behavior close to passivation feature.

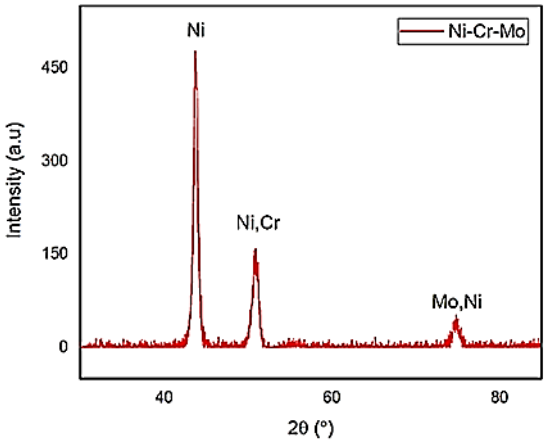
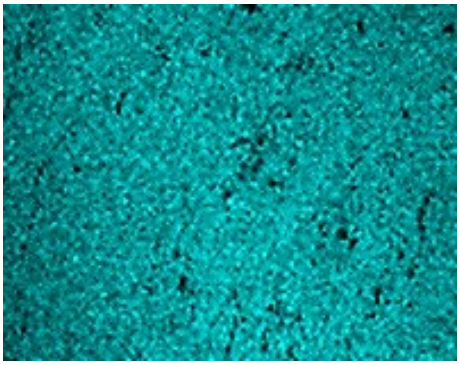
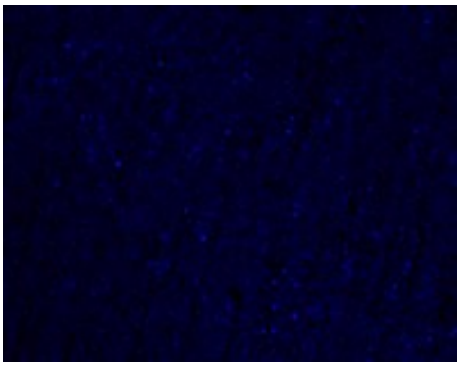


Figure 1. XRD patterns of the alloy.

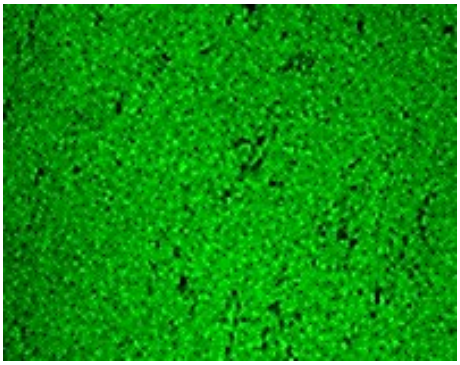
a



b



c



d

Figure 2. (a) Microstructure of Ni-Cr-Mo alloy; (b, c and d) SEM mapping of Cr, Mo and Ni respectively.

3.1. Micro Hardness and Electrochemical Corrosion Tester

In order to determine the final micro hardness value of Ni-Cr-Mo metal ceramic alloy, measurements were taken from five different surfaces of the sample and the final value was decided by taking the average of five measurements. (100 g load, 10 sn holding) Accordingly, the hardness values measured are; 342,1 kgf/mm^2, 353,5 kgf/mm^2, 367,6 kgf/mm^2, 384,4 kgf/mm^2 and 385.,1 kgf/mm^2. The final average micro hardness value was measured as 366,54 kgf/mm^2.

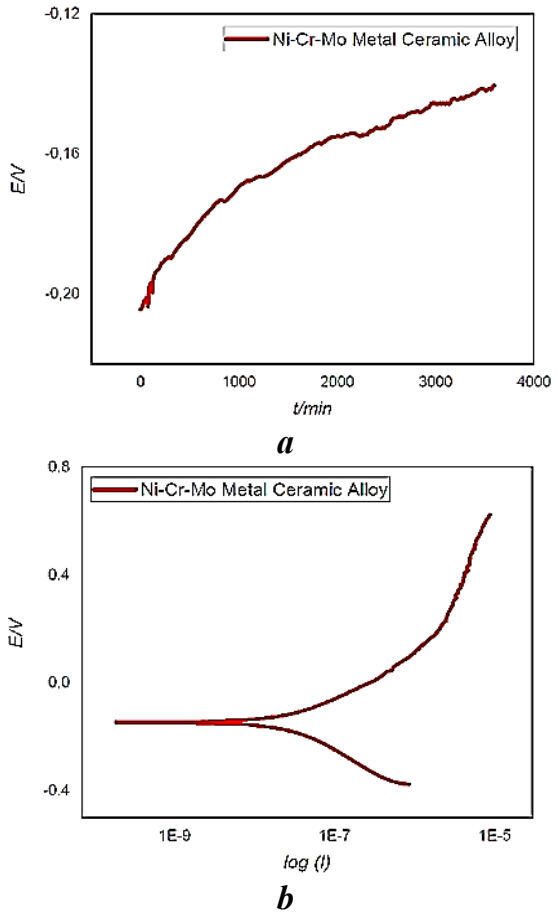


Figure 3. (a) open circuit voltage of Ni-Cr-Mo alloy, (b) Tafel extrapolation of Ni-Cr-Mo.

In Figure 3a, open circuit potential measurements of Ni-Cr-Mo metal ceramic alloy in ringer's solution for 40 minutes are shown. Ni-Cr-Mo metal-ceramic alloy has deviated positively and accomplished its measurements at higher potentials than it started. Samples exhibiting this behavior are due to the protective oxide layer composed on their surface. In consequence of the measurement, equilibrium with the solution and thermodynamic stability could not be reached completely. In future studies, a longer-term open circuit potential measurement can be performed for this alloy to investigate how it will behave. Figure 3b shows the graphical data resulting from the Tafel analysis. It is seen that Ni-Cr-Mo metal ceramic alloy is close to show passivation feature. It is seen that the protective layer formed on its surface has a strong adhesion and reaction to the electrolytic solution. It is seen that it exhibits a behavior close to passivation feature.

Table 3. The result of Tafel extrapolation of NiCrMo.

Variables	Values
Beta A	166,3e-3 *V/decade*
Beta C	201,6e-3 *V/decade*
Icorr	34,50 *nA*
Ecorr	-146,0 *mV*
Corrosion Rate	940,3e-3 *mpy*
Chi Squared	3,36E-01

4. CONCLUSION

Implants used in dental prostheses are produced from expensive metals and alloys that resist corrosion in terms of proper production and usage technique. For this purpose, the important thing is to produce alloy types that are inexpensive but of the same quality, or to examine existing alloys. The Ni63,4-Cr23,6-Si1,4-Mo11 alloy investigated in this study is found to meet the expected these properties. For this purpose, the homogeneous microstructural properties (Ni-Cr-Mo-Si) and annual corrosion value (940,3e-3 mpy) of the examined alloy were found. Ni63,4-Cr23,6-Si1,4-Mo11 metal ceramic dental alloy is suitable for use as dental prosthesis instead of expensive noble metals with its passive corrosion property and homogeneous structure.

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MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

The Impact of Probiotic Intervention during Developmental Cafeteria Diet Consumption on Social Behavior in Adulthood

Hikmet Taner TEKER[1], Gizem Hazan AKCAY[2], Seyma Nur CETINER[3] Aydogan BORA[4], Taha CEYLANI[5]

[1]*School of Medicine, Ankara Medipol University, Ankara, TÜRKİYE*
h.tanerteker@gmail.com —ORCİD 0000-0002-6621-3071

[2]*Faculty of Engineering and Architecture, Mus Alparslan University, Muş, TÜRKİYE*
g.hazan.caglayan@gmail.com—ORCİD 0000-0002-5885-7934

[3,4] *Vocational School of Health Services, Mus Alparslan University, Muş, TÜRKİYE*
s.cetiner@alparslan.edu.tr —ORCİD 0000-0002-8609-521X
a.bora@alparslan.edu.tr —ORCİD 0000-0003-1979-8692

[5]*Vocational School of Technical Sciences, Mus Alparslan University, Muş, TÜRKİYE*
t.ceylani@alparslan.edu.tr —ORCİD 0000-0002-3041-6010

Article Information

Article Types	Research Article
Received	05 August 2024
Accepted	20 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 67-74

Cite as: Teker, H. T., Akcay, G. H., Cetiner, S. N., Bora, A., Ceylani, T., "The Impact of Probiotic Intervention during Developmental Cafeteria Diet Consumption on Social Behavior in Adulthood", Hendese, Vol. 1, Issue 2, Pages 67-74, 2024.

Corresponding Author: Hikmet Taner TEKER

https://doi.org/10.5281/zenodo.13996497

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
RESEARCH ARTICLE

The Impact of Probiotic Intervention during Developmental Cafeteria Diet Consumption on Social Behavior in Adulthood

Hikmet Taner TEKER[*1], **Gizem Hazan AKCAY**[2], **Seyma Nur CETINER**[3], **Aydogan BORA**[4], **Taha CEYLANI**[5]

[*1]*School of Medicine, Ankara Medipol University, Ankara, TÜRKİYE*

[2]*Faculty of Engineering and Architecture, Mus Alparslan University, Muş, TÜRKİYE*

[3,4]*Vocational School of Health Services, Mus Alparslan University, Muş, TÜRKİYE*

[5]*Vocational School of Technical Sciences, Mus Alparslan University, Muş, TÜRKİYE*

(**Received:** 05.08.2024, **Accepted:** 20.10.2024, **Published Online:** 27.10.2024)

Keywords
Cafeteria diet,
SCD Probiotics,
Development period,
Social behavior test.

ABSTRACT

This study examines the ramifications of consuming a cafeteria diet during developmental stages and subsequent probiotic therapy on social behavior in adult male Wistar rats. The investigation involves four experimental groups: a control group, a probiotics-only group, a cafeteria diet group, and a cafeteria diet with probiotics supplementation group. From day 21 (weaning) today 56 (the end of the developmental period), the treatments were administered. Social behavior was assessed using a three-chambered apparatus to evaluate the time spent interacting with unfamiliar rats. The results displayed that consuming a cafeteria diet during development significantly altered social behaviors, as demonstrated by decreased interaction times with unfamiliar animals, which suggests increased anxiety or diminished sociability. Conversely, the probiotics-supplemented group, which consumed the cafeteria diet, displayed social behaviors that were more comparable to the cafeteria diet group. These findings indicate that a poor diet during critical growth periods can have detrimental effects on social interaction and suggest that probiotic supplementation may be able to mitigate these negative consequences. The study emphasizes the importance of early dietary interventions and gut microbiota modulation in maintaining social health and reducing the long-term consequences of an unhealthy diet.

Corresponding Author: h.tanerteker@gmail.com
Volume: 1 **Issue:** 2

Cite as: Teker, H.T., Akcay, G.H., Cetiner, S.N., Bora, A., Ceylani, T., "The Impact of Probiotic Intervention during Developmental Cafeteria Diet Consumption on Social Behavior in Adulthood", Hendese, Vol. 1, Issue 2, Pages 67-74, 2024.

Doi: 10.5281/zenodo.13996497

1. INTRODUCTION

A diet rich in processed and calorie-dense foods, often referred to as a cafeteria diet, serves as an established model for investigating the various health impacts that arise from dietary habits [1]. The developmental phases of life are especially susceptible to the influences of such dietary patterns, which can result in profound and lasting health ramifications over time [2]. These dietary habits negatively impact vital organs, including the liver, which plays a crucial role in metabolic processes and detoxification [3]. In Wistar rats, the administration of cafeteria diets during developmental stages rapidly induces obesity, with the effects being more pronounced than those observed with high-fat diets alone. The persistent consumption of foods that are high in calories disrupts the body's energy homeostasis, resulting in significant weight gain and an increase in various metabolic markers, which highlight the potential health hazards associated with such dietary practices [4]. One notable consequence of the cafeteria diet is the marked elevation in leptin levels, which indicates the early stages of leptin resistance, a condition that hampers the body's ability to regulate appetite and energy expenditure effectively. Furthermore, this diet leads to adverse alterations in lipid profiles, including increased cholesterol levels, which are indicative of potential cardiovascular risks. Although the cafeteria diet is designed to replicate the palatability and variety of a typical Western diet, it faces criticism due to the lack of consistency and standardization in its food components, which can lead to variability in experimental outcomes and complicate the interpretation of results [4]. Moreover, the persistent consumption of a cafeteria diet poses significant long-term risks to liver health, potentially predisposing individuals to the development of metabolic diseases in later stages of life [5]. Investigating these connections yields vital insights into the intricate relationships between diet, metabolism, and health outcomes. This research is instrumental in pinpointing therapeutic targets and developing strategies to counteract the detrimental effects of a cafeteria diet on liver function and overall metabolic homeostasis [6]. Additionally, diets rich in processed and high-energy foods can lead to significant disruptions in gut microbiota composition, exacerbate inflammatory responses, and contribute to liver damage. These adverse effects further underscore the potential health risks associated with prolonged consumption of a cafeteria diet [7].

The gut microbiome is essential for digestion and various metabolic functions, exerting a profound influence on the liver and other vital organs. Its role is pivotal in maintaining overall health and metabolic balance [8–11]. The gut microbiome is implicated in the pathogenesis of numerous liver diseases, including oxidative liver injury, chronic hepatitis B, hepatic steatosis, non-alcoholic steatohepatitis (NASH), cirrhosis, and hepatocellular carcinoma. These associations highlight the critical role of gut microbiota in liver health and disease [12]. Probiotics, which consist of beneficial microorganisms, can significantly ameliorate these liver conditions by modulating the gut microbiota, reducing systemic inflammation, and enhancing the integrity of the gut barrier. Through these mechanisms, probiotics positively influence liver health and contribute to overall metabolic stability [13, 14]. Administering probiotics during developmental stages has the potential to counteract the detrimental effects of a cafeteria diet on liver and metabolic health. These beneficial microorganisms work by modulating the gut microbiota, reducing inflammation, and enhancing gut barrier function, which collectively contribute to improved liver health and metabolic stability. Given the promising benefits of probiotics, future animal studies are of paramount importance. Such research will be essential for identifying potential therapeutic targets and interventions to mitigate the adverse impacts associated with a cafeteria diet. Through these investigations, valuable insights can be gained into the development of effective strategies for preserving liver and metabolic health. Additionally, regular use of probiotics may offer long-term health benefits by offsetting the negative consequences of diets high in processed and calorie-dense foods [15].

Based on existing research, we hypothesize that consumption of a cafeteria diet during critical developmental stages will negatively impact social behaviors in adult rats, manifesting as increased anxiety and reduced sociability. Furthermore, we propose that probiotic supplementation during these stages will mitigate these adverse effects by modulating gut microbiota, thereby promoting healthier social interactions and reducing anxiety-related behaviors. This study aims to elucidate the interplay between diet, gut health, and social behavior, offering insights into potential therapeutic strategies for addressing the behavioral consequences of poor dietary habits during development.

2. MATERIAL METHOD

2.1. Animal Studies

Male Wistar rats, 21 days old and recently weaned, were utilized as model organisms for the study. The rats were divided into four groups, each consisting of seven rats: the control group (n=7), the SCD Probiotics group (n=7), the cafeteria diet group (n=7), and the cafeteria diet with SCD Probiotics supplementation group (n=7). Treatments were administered until day 56, marking the end of the developmental period. SCD Probiotics were given orally via gavage at a dose of 3/2 mL (1 × 10^8 CFU) per day. The probiotic supplement used was Liquid Probiotic Supplement (Essential Probiotics XI - 500 ml, H.S. Code: 2206.00.7000) from SCD Probiotics, containing strains such as *Bacillus subtilis, Bifidobacterium bifidum, Bifidobacterium longum, Lactobacillus acidophilus, Lactobacillus bulgaricus, Lactobacillus casei, Lactobacillus fermentum, Lactobacillus plantarum, Lactococcus lactis, Saccharomyces cerevisiae, and Streptococcus thermophiles* [16]. All animals were provided with a standard rodent diet ad libitum, with the cafeteria diet given in addition to regular feeding, as detailed in Table 1. Weekly measurements of the animals' weights, food consumption, and cafeteria diet content were recorded, ensuring comparable initial average weights across all groups. The groups receiving the cafeteria diet were given identical diet products. Social behavior tests were conducted on both control and experimental groups at the end of the developmental period. All animals were housed in accordance with standard animal care protocols in clear Plexiglas cages (7 rats per cage) under a 12-hour light/dark

cycle at a constant temperature of 21 °C. No rats died or were excluded from the study. The study was approved by the Bingöl University Animal Experiments Local Ethics Committee (meeting date: 29.06.2021, approval number: 2021/03).

2.2. Behavioral Test

2.2.1. Social behavioral test

The social behavior testing apparatus comprises three rectangular Plexiglas chambers, each separated by partitions featuring small openings for accessibility. To begin the experiment, rats were placed in the central chamber with the doors closed, allowing for a 5-minute acclimatization period. Following this initial phase, an unfamiliar rat, matched by strain and sex, was placed inside an inverted wire cup within one of the outer chambers. Conversely, the other outer chamber contained an empty wire cup. The doors to the outer chambers were then opened, granting the experimental rat the freedom to explore all three chambers for a duration of 10 minutes. Throughout this exploration period, a video camera positioned above the apparatus recorded the amount of time the experimental rat spent in each chamber. This setup enabled the assessment of the rat's social interaction tendencies and preferences based on its exploratory behavior in the presence of a novel conspecific and an empty cup.

In the third phase of the test, a second unfamiliar rat (stranger 2) was placed in the previously empty wire cup. The experimental rat was again allowed to explore all three chambers for 10 minutes. The time spent in each chamber was recorded using the same video camera setup. This test was designed to assess the social interaction preferences and novelty response of the experimental rats [17].

2.3. Statistic

To statistical evaluations and graphical representations of the results were conducted using GraphPad Prism 10.0 software (GraphPad, USA). The data analysis involved the application of an unpaired t-test and one-way ANOVA to assess the significance of differences among various groups. These groups included the control group (Cnt), the group receiving SCD Probiotics (Prb), the cafeteria diet group (Cd), and the cafeteria diet group supplemented with SCD Probiotics (CdPrb). The levels of statistical significance were set at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$. The results are expressed as mean values accompanied by the standard error of the mean (SEM), providing a clear representation of the data variability and reliability. This comprehensive statistical approach ensured robust analysis and accurate interpretation of the experimental outcomes.

Table 1. The ingredients of the cafeteria diet

Energy and Food Ingredients (100)	Total (kcal)	Total fat (g)	Total Carbohydrate (g)	Protein (g)	Sugar (g)
Control Diet					
SC 7001 (Harley)	382	4	54	25	0
CAF Diet					
Crackers					
Çay Keyfi (Eti)	462	20.4	67.8	5.8	28.5
Cookies					
Hoşbeş (Eti)	493	24.5	63.9	7.6	28.5
Hanımeller (Ülker)	427	18.1	62.1	3.9	25.0
Nestlé Crunch	500	26	67	5	55
Cereals					
Nesquik mısır gevreği (Nestle)	372	4.1	76.1	7.6	30.7
Chips					
Lays Wavy (Frito-Lay)	536	36	54	7	0
Lays Klasik (Frito-Lay)	529	33	51	7.0	0
Doritos (Frito-Lay)	491	24.5	60.5	7.2	2.3

3. RESULTS

3.1. The Second Phase of the Test

3.1.1. Comparison of time spent in the empty cage between control and experimental groups

In the first phase of this test, each rat was placed in a test apparatus with three chambers: an empty cage, a cage with an unfamiliar rat, and a central chamber. The focus of the graph is on the time spent by the rats in the 'empty' cage compared to the cage with the first unfamiliar animal (Figure 1).

The control rats (Cnt), which received a standard diet, spent a certain amount of time in the empty cage, providing a baseline for comparison against the other groups. Rats supplemented with probiotics (Prb) in addition to their standard diet may show differences in the time spent in the empty cage, reflecting the potential influence of probiotics on social behavior and curiosity. Rats fed a cafeteria diet (Cd), which is high in processed and energy-dense foods, are likely to exhibit altered behavior due to the dietary impact on their development. The time spent in the empty cage for this group may indicate decreased social interaction or increased anxiety. The group received a cafeteria diet supplemented with probiotics (CdPrb). The comparison of time spent in the empty cage for this group is critical to understanding the mitigating effects of probiotics on the adverse impacts of a cafeteria diet.

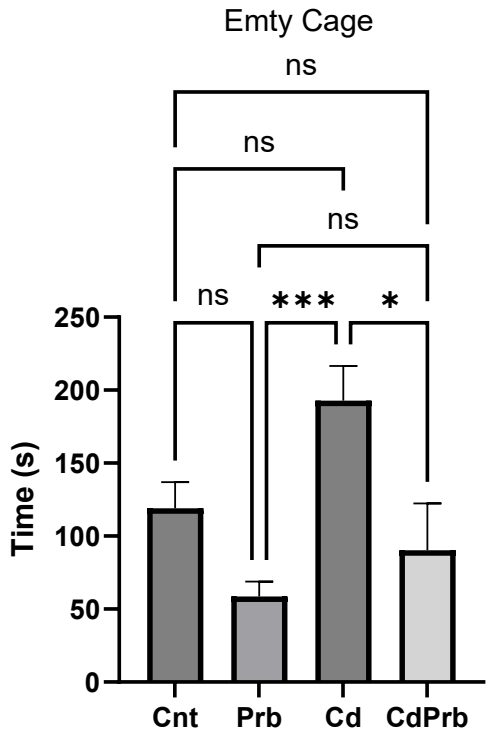

Figure 1. The impact of a cafeteria diet, SCD Probiotics supplementation, and the combined effect of SCD Probiotics during a cafeteria diet on social behavior was evaluated through a social behavioral test. Comparison of time spent in the empty cage. The data were analyzed using One-way ANOVA was conducted to analyze the data. Values were expressed as mean ± SEM, with n = 7 per group. Statistical significance was determined at $p \leq 0.05$* and $p \leq 0.001$***, with ns indicating non-significant results. The groups included were Cnt (control), Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

The graph illustrates the behavioral tendencies of the rats, specifically focusing on their preference for the empty cage over the cage with an unfamiliar rat. Significant differences between the groups would suggest that diet and probiotic supplementation during development have profound effects on social behavior in adulthood. For example, a higher time spent in the empty cage by the Cd group compared to the Cnt group might indicate reduced sociability or increased stress levels due to the cafeteria diet. Conversely, if the CdPrb group shows a similar time spent in the empty cage as the Cnt group, it could indicate that probiotics counteract the negative effects of the cafeteria diet.

3.1.2. Comparison of time spent in cage with the first unfamiliar animal between control and experimental groups

This comparison focuses on the time spent by rats in the cage containing the first unfamiliar animal, relative to the empty cage and the central chamber (**Figure 2**). The purpose of this comparison is to understand how different diets and probiotic supplementation influence social interaction behaviors. Control rats (Cnt) are expected to display baseline social interaction behaviors, spending a balanced amount of time exploring the cage with the unfamiliar animal, indicating normal curiosity and social behavior. Probiotic-supplemented rats (Prb) may exhibit increased or more balanced social interactions due to the potential positive effects of probiotics on gut health and behavior. The time spent in the cage with the unfamiliar animal will highlight these effects. Rats on a cafeteria diet (Cd) might show altered social behaviors, potentially spending less time in the cage with the unfamiliar animal due to the diet's impact on anxiety and sociability. This group provides insight into how an unhealthy diet affects social interaction. Cafeteria diet with probiotics group's (CdPrb) behavior is crucial in understanding whether probiotics can mitigate the negative effects of a cafeteria diet on social behavior. An increase in time spent in the cage with the unfamiliar animal compared to the Cd group would suggest that probiotics help maintain or restore normal social behaviors.

This comparative analysis helps in understanding how early dietary interventions, combined with probiotic supplementation, influence social behaviors and potentially mitigate negative developmental impacts caused by poor diets.

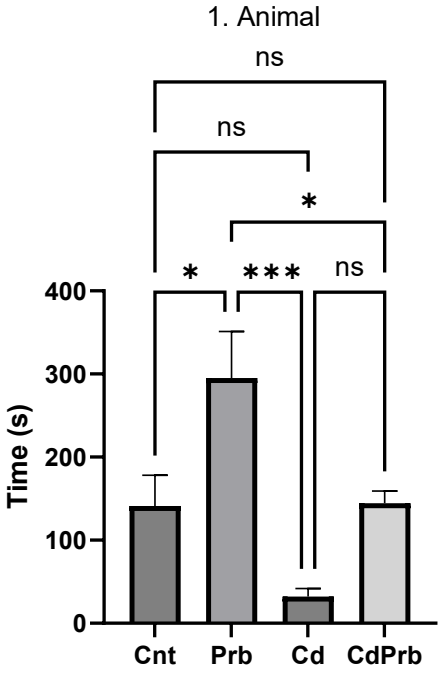

Figure 2. The impact of a cafeteria diet, SCD Probiotics supplementation, and the combined effect of SCD Probiotics during a cafeteria diet on social behavior was evaluated through a social behavioral test. Comparison of time spent in cage with the first unfamiliar animal. One-way ANOVA was conducted to analyze the data. Values were expressed as mean ± SEM, with n = 7 per group. Statistical significance was determined at $p \leq 0.05$* and $p \leq 0.001$***, with ns indicating non-significant results. The groups included were Cnt (control), Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

The comparison in the graph demonstrates the rats' social preferences and willingness to interact with an unfamiliar animal. Significant differences between groups indicate how early dietary interventions and probiotic supplementation impact social behavior in adulthood. If the Cd group spends significantly less time with the unfamiliar animal than the Cnt group, it would suggest increased anxiety or reduced sociability due to the cafeteria diet. Conversely, if the CdPrb group spends more time with the unfamiliar animal than the Cd group, it would indicate that probiotics mitigate the adverse effects of the cafeteria diet.

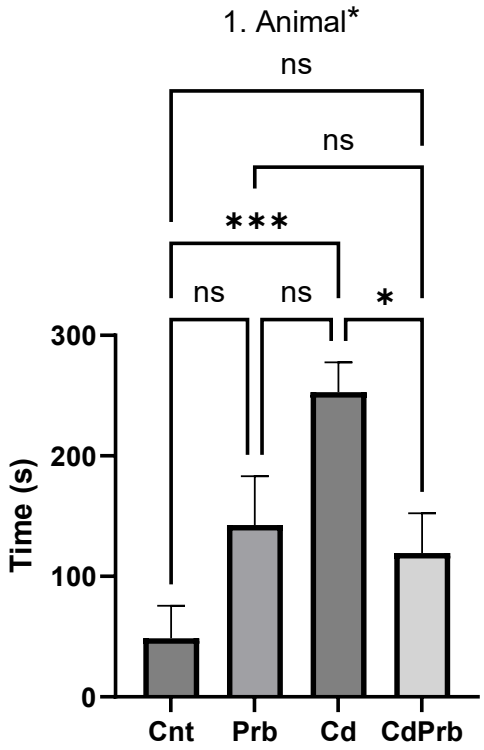

Figure 3. The impact of a cafeteria diet, SCD Probiotics supplementation, and the combined effect of SCD Probiotics during a cafeteria diet on social behavior was evaluated through a social behavioral test. Comparison of time spent in cage with the first unfamiliar animal in the third phase of the test. One-way ANOVA was conducted to analyze the data. Values were expressed as mean ± SEM, with n = 7 per group. Statistical significance was determined at $p \leq 0.05$* and $p \leq 0.001$***, with ns indicating non-significant results. The groups included were Cnt (control), Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

3.2. The Third Phase of the Test

3.2.1. Comparison of time spent in cage with the first unfamiliar animal between control and experimental groups

In the third phase of the test, the time spent by the rats in the cages containing either the first unfamiliar animal (introduced in the initial phase) or a new, second unfamiliar animal is measured (**Figure 3**). This comparison aims to determine whether the rats prefer to spend more time with an animal they have already encountered or with a completely new animal. The control group rats' behavior serves as a baseline for normal social interaction. The time spent in the cage with the first unfamiliar animal versus the second unfamiliar animal will indicate their preference for familiarity or novelty. Rats in the probiotic group (Prb) may exhibit different social preferences due to the influence of probiotics on gut health and behavior. Comparing their time spent with the first unfamiliar animal to the second can highlight the effects of probiotics on social memory and preference. The cafeteria diet group (Cd) is expected to show altered social behavior due to the diet's impact on their development. The preference for the first unfamiliar animal versus the second can provide insights into how an unhealthy diet affects social interaction and memory. Cafeteria diet with probiotics group (CdPrb) is crucial in understanding whether probiotics can mitigate the negative effects of a cafeteria diet on social behavior. If these rats spend more time with the first unfamiliar animal compared to the second, similar to the control group, it would suggest a positive impact of probiotics.

The graph illustrates the time each group of rats spends in the cage with the first unfamiliar animal during the second phase of the test. Significant differences between groups can indicate the impact of diet and probiotic supplementation on social preferences. For example, if the Cd group spends less time with the first unfamiliar animal compared to the Cnt group, it suggests a reduced preference for familiarity, potentially due to increased anxiety or impaired social memory. Conversely, if the CdPrb group shows a similar pattern to the Cnt group, it suggests that probiotics help restore normal social behavior despite the cafeteria diet.

3.2.2. Comparison of time spent in cage with the second unfamiliar animal between control and experimental groups

In the third phase of the test, the time spent by the rats in the cage containing the second unfamiliar animal, which they encounter for the first time during this phase, is measured (Figure 4). This comparison aims to assess the rats' inclination towards novelty and their social interaction behaviors in the presence of a new animal. The control group (Cnt) rats provide a baseline for normal exploratory and social behaviors. Their time spent in the cage with the second unfamiliar animal indicates their natural tendency to interact with new conspecifics. Rats in the probiotic group (Prb) may exhibit enhanced social behaviors and curiosity due to the positive effects of probiotics on gut-brain interaction. Their time spent with the second unfamiliar animal will highlight these potential behavioral changes. The cafeteria diet group (Cd) might show decreased social interaction or increased anxiety, reflected in their time spent with the second unfamiliar animal. This comparison provides insight into the impact of an unhealthy diet on novelty preference and social behavior. Cafeteria diet with probiotics group (CdPrb) is critical for understanding whether probiotics can mitigate the negative effects of a cafeteria diet on social behavior. If these rats spend more time with the second unfamiliar animal compared to the Cd group, it suggests that probiotics help maintain or restore healthy social behaviors despite the dietary intervention.

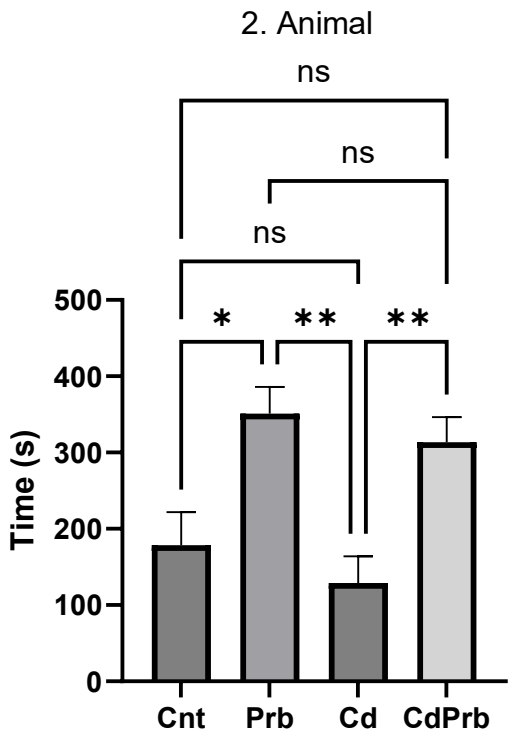

Figure 4. The impact of a cafeteria diet, SCD Probiotics supplementation, and the combined effect of SCD Probiotics during a cafeteria diet on social behavior was evaluated through a social behavioral test. Comparison of time spent in cage with the second unfamiliar animal. One-way ANOVA was conducted to analyze the data. Values were expressed as mean ± SEM, with n = 7 per group. Statistical significance was determined at $p \leq 0.05$* and $p \leq 0.001$***, with ns indicating non-significant results. The groups included were Cnt (control), Prb (SCD Probiotics), Cd (Cafeteria diet), and CdPrb (cafeteria diet with SCD Probiotics supplementation).

The graph demonstrates the time each group of rats spends in the cage with the second unfamiliar animal during the second phase of the test. Significant differences between groups can indicate the impact of diet and probiotic supplementation on novelty preference and social interaction. For example, if the Cd group spends significantly less time with the second unfamiliar animal than the Cnt group, it may suggest increased anxiety or reduced interest in social novelty due to the cafeteria diet. Conversely, if the CdPrb group shows similar behaviors to the Cnt group, it suggests that probiotics help counteract the negative effects of the cafeteria diet on social behavior.

4. DISCUSSION

The present study intended to examine the consequences of a cafeteria diet consumed during developmental stages and the subsequent impact of probiotic therapy on social behaviors in adult Wistar rats. The results indicate that a cafeteria diet, which is rich in processed and energy-dense foods, has a significant negative effect on social interactions, as evidenced by a decrease in time spent with unfamiliar rats and an increase in anxiety-related behaviors. These findings are consistent with previous research that has shown the detrimental effects of high-calorie, nutrient-poor diets on cognitive and social functions. It is worth noting that probiotic supplementation during development appears to mitigate these adverse outcomes, suggesting a protective role for probiotics in maintaining social behavior and reducing anxiety. This study emphasizes the importance of early dietary interventions and supports the potential therapeutic benefits of probiotics in counteracting the negative effects of poor dietary habits on social and behavioral health.

Our research results show that a diet consisting of cafeteria food during developmental stages has a significant negative impact on social behaviors in adult Wistar rats. However, the use of probiotic supplements can mitigate these adverse effects. The SCD Probiotics supplement, which contains strains such as *Bacillus subtilis*, *Bifidobacterium bifidum*, and various species of *Lactobacillus*, appears to play a crucial role in this improvement. This finding aligns with the growing body of literature that emphasizes the significant role of gut microbiota in shaping brain function and behavior. Probiotics are known to affect the gut-brain axis, which in turn influences behavior and cognitive functions [18]. In addition, in a recent study conducted by our team, it was demonstrated that the combined administration of SCD Probiotics and Tauroursodeoxycholic Acid (TUDCA) is more effective in alleviating anxiety-like behavior in aged rats [19]. The inclusion of *Bacillus subtilis* in our probiotic formulation is particularly noteworthy, as this bacterium has been shown to improve gut health and immune responses. *Bacillus subtilis* also produces bioactive compounds that can modulate the central nervous system, which could explain the observed improvement in social behaviors in our study [20]. Specifically, *Bacillus subtilis* can produce neurotransmitter-like substances that may directly or indirectly affect brain function, leading to enhanced social interactions and reduced anxiety.

Emerging evidence highlights the critical role of gut microbiota in modulating host behavior, particularly through the gut-brain axis, influencing cognitive functions, emotional regulation, and responses to stress [21]. *Bifidobacterium bifidum* is a vital component of the SCD Probiotics, as evidenced by previous research demonstrating its ability to reduce inflammation and improve gut barrier function, which are crucial factors for overall health and behavior [22]. *Bifidobacterium bifidum*'s anti-inflammatory properties may contribute to the observed reduction in anxiety-like behaviors in the probiotic-supplemented groups [23]. By reducing systemic inflammation, *Bifidobacterium bifidum* may also help create a more favorable environment for neurodevelopment, thereby positively impacting social behavior.

Lactobacillus species, including L. acidophilus, L. bulgaricus, L. casei, L. fermentum, and *L. plantarum*, which are present in the SCD Probiotics, have been extensively studied for their positive effects on mental health and behavior. *L. rhamnosus*, for example, has been shown to reduce anxiety and depression-related behaviors in mice, possibly through modulation of GABA receptors [24]. Although our study did not specifically include *L. rhamnosus*, the presence of related *Lactobacillus* species suggests similar mechanisms may be at

play, contributing to the enhanced social behaviors observed in the CdPrb group. The presence of multiple Lactobacillus species may create a synergistic effect, enhancing the overall efficacy of the probiotic supplementation in improving social behavior. Additionally, a recent study found that the reduction of specific Lactobacillus species, which play a key role in T cell differentiation to support the host immune system, contributes to stress-induced social-avoidance behavior [25].

The period of development is of paramount importance for the establishment of long-lasting health and behavior patterns. Our findings are consistent with those reported by Ait-Belgnaoui et al. (2012), who found that early probiotic intervention during critical periods can positively impact brain development and function [26]. More recent studies further support this, showing that probiotics can modulate the gut microbiota to reduce social avoidance behaviors induced by stress [27-28-29]. Another study found that probiotic supplementation during development improved social behavior by increasing the abundance of beneficial bacteria and promoting gut-brain communication [30]. Our study reinforces the notion that modulating the gut microbiota during this crucial phase can have lasting effects on social behavior, providing a preventive strategy against the deleterious effects of poor dietary habits. These results highlight the significance of early dietary interventions and suggest that probiotics could serve as a valuable tool in fostering healthy neurodevelopment and social behavior.

5. CONCLUSION

In conclusion, the SCD Probiotics supplement appears to mitigate the adverse effects of a cafeteria diet on social behavior in adult rats, likely due to the combined actions of its constituent bacterial strains. These findings underscore the significance of gut health in influencing behavioral outcomes and highlight the therapeutic potential of probiotics in counteracting the negative impacts of unhealthy diets during critical developmental periods. Further research is needed to elucidate the specific mechanisms involved and to investigate the potential of probiotic interventions in human populations. Gaining a deeper understanding of the precise interactions between diet, probiotics, and neurodevelopment could pave the way for new strategies in the prevention and treatment of diet-related behavioral disorders.

ACKNOWLEDGEMENTS

We express our gratitude to Adem Kurtcuoğlu for his contributions.

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MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

Comparison of Structural Damages Observed in Kahramanmaraş Earthquakes with the Damage Types in The Regulations

Hikmet TUTAR[1]

[1]*Vocational School of Technical Sciences, Mus Alparslan University, Muş, TÜRKİYE*
h.tutar@alparslan.edu.tr — ORCID 0000-0002-2758-3635

Article Information

Article Types	Research Article
Received	04 February 2024
Accepted	20 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 75-84

Cite as: Tutar, H., "Comparison of Structural Damages Observed in Kahramanmaraş Earthquakes with the Damage Types in The Regulations", Hendese, Vol. 1, Issue 2, Pages 75-84, 2024.

Corresponding Author: Hikmet TUTAR

https://doi.org/10.5281/zenodo.13996504

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
RESEARCH ARTICLE

Comparison of Structural Damages Observed in Kahramanmaraş Earthquakes with the Damage Types in The Regulations

Hikmet TUTAR[*1]

[*1] *Vocational School of Technical Sciences, Mus Alparslan University, Muş, TÜRKİYE*

(**Received:** 04.02.2024, **Accepted:** 20.10.2024, **Published Online:** 27.10.2024)

Keywords
Eartquake,
Kahramanmaraş,
Pazarcık,
Soil,
Damage

ABSTRACT

It is reported that a significant number of buildings were damaged in two major earthquakes with a magnitude of Mw=7,7 in Pazarcık, Kahramanmaraş, Turkey on 06.02.2023 and with a magnitude of Mw=7,6 in Elbistan, Kahramanmaraş, Turkey on the same day. It has been stated that the effects of the earthquakes were felt in 10 provinces (Kahramanmaraş, Hatay, Gaziantep, Diyarbakır, Şanlıurfa, Elazığ, Malatya, Adana, Osmaniye and Kilis), and there were many casualties in these 10 provinces where more than 20,000 buildings collapsed. It is reported that in the earthquakes that took place on 06.02.2023, structures built according to the 2018 Earthquake Regulation rules in force for Turkey also suffered significant damage and even collapsed. Although the current investigations are focused on buildings, bridges, prefabricated structures, water structures that provide transportation in this earthquake should also be examined and reported. Based on the rough observations made, many structures were knocked down without any damage due to soil liquefaction due to the ground conditions of many buildings not being considered. Another issue is the detection of demolitions because the structures before the current earthquake regulation, which has been talked about for years but could not be realized, were not strengthened based on the current earthquake regulation. The causes of damage were determined in the investigations. It has been determined that the newly built structures do not comply with the current earthquake regulations. Over 2000 buildings were examined in 10 cities to compare them with the regulations on partially or completely demolished buildings. As a result of these investigations, the reasons for the collapse of the buildings were determined.

Corresponding Author: h.tutar@alparslan.edu.tr
Volume: 1 **Issue:** 2

Cite as: Tutar, H., "Comparison of Structural Damages Observed in Kahramanmaraş Earthquakes with the Damage Types in The Regulations", Hendese, Vol. 1, Issue 2, Pages 75-84, 2024.

Doi: 10.5281/zenodo.13996504

1. INTRODUCTION

After two devastating earthquakes of 7,7 and 7,6 magnitude that occurred in Kahramanmaraş [1], collapses occurred in many structures in Hatay, Gaziantep, Adıyaman, Diyarbakır, Malatya, Şanlıurfa, Osmaniye, Kilis and Adana [2]. Based on the rough observations made, the following conclusions were reached. Although Kahramanmaraş-Pazarcık is far from the earthquake center compared to Kahramanmaraş province, Hatay province has suffered more structural damage due to ground conditions. When the structures built on the silt-sand mixture transported and stored from the mountains for millions of years in the coastal area were exposed to an earthquake, the ground liquefaction caused a large part of the structures to topple or the structures to sink [3].

The Antakya-Kahramanmaraş graben is one of the areas where many tectonic structures coexist and where tectonic activity is intense. Except for the Arabian plate, which continues its activity, this area is under the influence of the Dead Sea and East Anatolian Faults and the African plate Cyprus Arc. The city of Hatay-Antakya is stretched under the influence of the Dead Sea Fault, which shaped and continues to shape the south of the Graben area. Therefore, the city has a very high earthquake risk. Seismic activities and fault traces that occurred in the past prove that this graben is under constant risk [4].

In energy-related disasters such as earthquakes, the structure is expected to absorb energy in a controlled manner. The first damage that occurs in structures is expected to occur in the weakest link of the chain (wall) in the hollow curtains. Cracks that occur in structures where stiffness is damped in the form of force-displacement describe displacement. However, these displacements in the structural element and the geometric shape of the displacement determine the damage status and resistance of the structure. The displacement effect occurring in structures is like a force vector. The size and direction of shear, bending and torsion cracks and the connection status of the elements are important [5].

The shape of the damages detected in the inspections made on the in-situ reinforced concrete structures in the field after the consecutive earthquakes in the province of Kahramanmaraş were examined. In general, the use of low-strength concrete, missing or faulty column-beam connections, deficiencies in the wrapping reinforcement that the craftsmen had difficulty in making and avoided making, soft floors and short columns-beams during the design period, errors in the arrangement of shear walls to increase the function of the workplace, the formations at the points where the beams are connected to the walls-columns. Faults in bending and shearing have been observed as causes of damage.

Sections in source [6] are given in the region. The first of these sections include the units of the Amanos Mountains from the Precambrian to the Mesozoic, and the second includes the alluvial and Quaternary sediments located close to the coasts. The transition zone from the mountains to the coast was covered with serpentines. The structures under investigation were located on Quaternary sediments and undifferentiated clastic rocks. [6]. Studies by Türkmen et al. [7] revealed that the coast in the Dörtyol coastal plain consists of components of the basement rocks. The cross-section of the plain shows that tertiary conglomerates lie beneath the Quaternary alluvium. Alluvial fans on the mountain slopes, where streams emerge from narrow valleys and enter the wide plain, are characterized by coarse materials. Quaternary alluviums in the coastal region were formed by physical processes within river channels and consist of gravel, sand, and clay. Deliçay, Kocaçay, and Payas Streams carry Quaternary alluviums to the coast. While rocks and coarse deposits are mapped on higher slopes, lower and gentler slopes consist mostly of finer-grained deposits, more specifically sand and clay [8].

Geomorphological, lithological, hydrogeological, and tectonic features of an area constitute the local geotechnical (ground) features of that area. It was stated that the same type of structures in areas with different soil properties were damaged at different levels of earthquake intensity at the same magnitude of seismic activity. This situation is seen when the acceleration and earthquake intensities of historical and instrumental earthquakes are examined. This situation, on the other hand, changes in the form of damping or amplification according to the characteristics of the soils as the earthquake waves pass through the soils. Considering the causes of damage to the structures; as the effects of soil properties; liquefaction, soil enlargement, collapse and settlement on the ground, deterioration of stability on the slopes and the ground rising and overturning the structures [9].

Due to the accumulation of alluviums formed by rivers or seas for millions of years to form warehouses, the high groundwater levels along the Asi River, and the fact that the groundwater is filled with seawater in the areas close to the sea, these soil features increase the earthquake waves and create soil amplification in a possible earthquake. In this case, the intensity of the earthquake increases by 2-3 degrees. Liquefaction of silt sand and sometimes gravel in the ground may occur. In short, when the silt-sand-gravel-water and seismic activity required for ground liquefaction come together, if the ground is not rehabilitated with a foundation type that has enough leather foundations for the structure, one of the wrestlers picks up the other and knocks it down like he hits the ground on his back. Looking at the boreholes drilled to determine the foundation and ground parameters of the buildings, it was determined that the groundwater level varied between 3 and 7.5 m. At the same time, it was determined from the drilling logs opened at these levels that these soils were composed of silty and clayey sands. It has been determined that the risk of liquefaction in these areas in a possible earthquake is quite high [10].

The basis for the confirmation of this claim is that there is less structural damage in mountainous areas. Another reason is that most of the building stock was built according to the 1975 earthquake code before 2000, and the buildings between 2000-2007 were built according to the 1998 earthquake code, and the buildings after 2007 were built according to the 2007 earthquake regulations, naturally, they were not built according to the 2018 earthquake regulations. The design earthquakes of

buildings built according to the 2007 earthquake regulations do not meet the 2018 earthquake regulations. Another problem is that the earthquake code rules are rarely applied in newly constructed buildings. The regulations updated in 2018 are not implemented in the buildings constructed after the 2018 earthquake regulations. However, although earthquake regulations have changed, only a few existing buildings have been retrofitted. For example, a collapsed building in Adana was damaged in an earthquake 25 years ago, but it continued to be used without any reinforcement [11]. The symbols used in damage detection are given in Table 1 below.

Table 1. Damage symbols and types

Damage symbol	Damage Type	Crack Width (w)	Pressure Damage Type
O	Undamaged	w≤0.5mm	
A	Slightly damaged	0.5mm≤ w ≤3mm	Shell crush
B	Medium		Crust
C	Heavy		
D	Too heavy		Reinforcement buckling kernel crush

Damage detection was examined in two ways: from outside and inside the building. In structures where significant collapses have occurred (complete or partial), detailed examination is required on the soils that are at the stage of collapse due to complete collapse or rotation. During the examination of this structure, the safety of the examiner must be ensured. The personnel who will carry out this situation, which requires expertise, must ensure the safety of the technical staff [4]. For this reason, the building was examined from the outside and if there was no risk of collapse in a possible or imminent earthquake, this structure was subjected to a preliminary examination from the inside. General crack analyses of the main carrier and non-carrier elements were carried out.

Since we have limited resources in world conditions, optimum designs are made based on minimum material and minimum strength. Due to reasons such as lack of qualified personnel, the safety coefficient for steel is increased by 15%, while the calculations are made by increasing it by 50% for concrete. However, due to the incorrect knowledge of this known information in practice, most of the time, the workmanship of the structure is very relaxed [12].

In general, the leading cause of the collapse of buildings is the failure to meet the capacities demanded by the buildings. It is the inadequacy of cutting and bending capacity. The relations of the building elements with each other are like a group pulling a hatay, if there are weak individuals in the group, it pulls all the stresses on it. If there are strong individuals in the group, it tries to crush all other elements.

Damage degrees are defined as follows. Undamaged: The building has not suffered any damage due to a natural disaster, Slightly Damaged: Fine plaster cracks, plaster flaking, 1-4 mm wide fine cracks on the walls, cracks up to 10 mm in filling and gable walls and partial falls, Medium Damage: 5-5 mm on load-bearing walls. Significant cracks 10 mm wide, partial collapse and separation in partition gable and infill walls, Severely Damaged: Widespread shear fractures wider than 10 mm in load-bearing walls, separation and crushing at building corners, conical spills, separation of the building from the vertical, Collapse: In the building carrier system Partial or complete collapse, partial or complete collapse of the roof. Moreover; Very Heavily Damaged (Buildings to be Demolished Immediately): These are buildings in which the load-bearing elements of the building have been partially or destroyed by permanent displacement to a large extent due to the earthquake. These buildings, which cannot be used in any way, cannot be entered and belongings cannot be evacuated. At the end of general aftershocks, this building is removed as debris [11].

Very Heavily Damaged (Buildings to be Demolished Immediately): These are buildings in which the load-bearing elements of the building have been partially or destroyed by permanent displacement largely due to the earthquake. These buildings, which cannot be used in any way, cannot be entered and belongings cannot be evacuated. At the end of general aftershocks, this building is removed as debris.

Within the scope of this study, we examined 11 cities and districts. The purpose of this study determines whether the fracture and damage of the structures specified in the regulations and literature occurred in the Kahramanmaraş earthquake. whether old structures accommodate these fracture patterns. I tried to find out whether the buildings built after the 2018 earthquake regulations meet these damage types and record them in the literature. By combining our field and experience, we revealed the devastating causes of the earthquake.

2. SEISMIC RESPONSE OF REINFORCED CONCRETE AND OTHER STRUCTURES

2.1. Structure Soil Interation

The examined building is in the city center of Adıyaman-Gölbaşı district. The region is located on the lake-formed alluvial deposits of a pull-apart basin connected to the Gölbaşı-Türkoğlu segment of the Eastern Anatolian Fault Zone (EAFZ). The buildings in this region were designed considering earthquake regulations. However, although it was stated in the ground reports, that not enough precautions were taken for the foundations, which had devastating consequences for this area within the Gölbaşı settlement area. Beyond the construction quality, the collapse of buildings due to deep ground behavior such as ground liquefaction, loss of bearing capacity due to loss of strength in the ground, ground deformations - sand jets and lateral spreading, as well as significant damage such as tilting of buildings without any structural damage or level movement and deformations on train tracks.

We did not look at the number of floors of the buildings. We mostly looked at how buildings collapsed and their durability. As seen in Figure 1, there was no need for structural examination of the buildings that were tilted due to liquefied soil. because there was no structural break or collapse other than

the collapse and overthrow of the structure (Figure 2).

Figure 1. A building that collapsed due to soil liquefaction but remained intact based on its elements.

Figure 2. A building that moves vertically due to soil liquefaction - sand boiling but remains intact with its elements.

2.2. Soft Story Effects in Ribbed Slab Constructions

The ground floors are designed higher than the upper floors, the wall areas on the upper floors are high, and heavy overhangs are created in the building.

Figure 3. The building built in 2022 in Malatya's Bostanbaşı Neighborhood.

Figure 3 The structure, which was built in 2022 in Malatya's Bostanbaşı Neighborhood, but collapsed due to the soft floor in two major earthquakes of 7.7 and 7.6 magnitudes that occurred in Kahramanmaraş on February 6, 2023. It is seen that the lower part of the collapsed structure in Malatya, which is widely seen on social media, has collapsed. However, the top of the building remains obliquely standing on a pile of dust and rubble. This structure was built last year, and advertisements seen on social media say that the building was "built under the latest earthquake regulations". All materials and workmanship were claimed to be of "first-class quality". The fact that the building is newly constructed requires that it be constructed under the 2018 earthquake regulations. In this regulation, it is stated that high-quality concrete reinforced with steel reinforcements should be used in buildings in areas with earthquake risk.

Figure 4. A soft floor incident that occurred in the city center of Iskenderun

In Figure 4. soft floor incident that occurred in the city center of Iskenderun. It is envisaged that the columns and beams will be effectively distributed and arranged with shear concrete in both directions to meet the horizontal loads to meet the impact of the earthquake. However, we do not have information about the materials and workmanship that determine the construction standards used in this building.

2.3. Short Columns Effects

Illustrated figure 4, since the ground floors are raised more than necessary to sell them at a better price, band windows should be opened in the curtains of the basements surrounded by curtains to provide adequate illumination of the basement. As a result of examining the building photographs above, it was seen that the basement floor was surrounded by curtains and windows were opened from these curtains. It was understood that due to the opening of these windows, a short column effect occurred, and the building collapsed. Figure 5. Despite the warnings made two years ago in Malatya, the building where the columns were cut for the market collapsed in the earthquake.

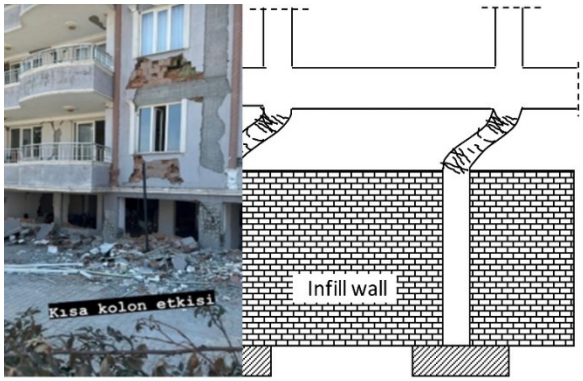

Figure 5. Despite the warnings made two years ago in Malatya, the building where the columns were cut for the market collapsed in the earthquake.

2.4. Strong Beam and Weak Column Behavior

If the beams are stronger than the columns, the beams are solid, like a layered sandwich, but there is no sign of the columns. Figure 6. A collapsed building in the Malatya Özalper Neighborhood collapsed due to a weak column-strong beam.

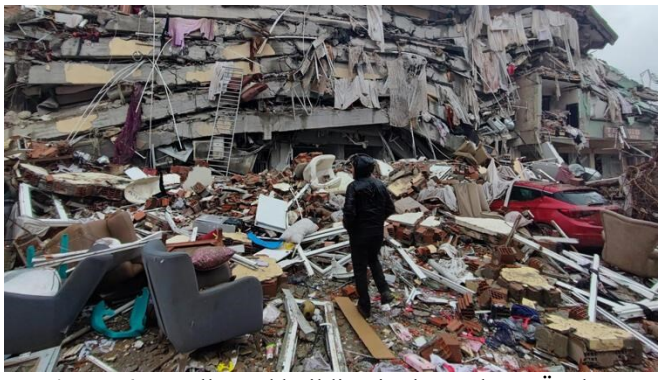

Figure 6. A collapsed building in the Malatya Özalper Neighborhood collapsed due to a weak column-strong beam.

2.5. Historical Building

Historical buildings are the memory of societies and nations, they are visual historical documents that talk about the culture, civilization and historical memory of civilizations. These structures are important in connecting the past of society to the future and showing the progress and lifestyle in the field of art and culture (Figure 7). The Historical Arasa Mosque in the Kahramanmaraş earthquakes.

The masonry construction technique has been used in the construction of buildings all over the world for years. In general, wood, adobe, brick and stone are among the oldest building materials. These materials are still used today due to some of their cost effectiveness, durability, local availability, sound insulation properties and restoration purposes. Earthquake regulations for the protection, design and construction of such structures have generally been updated many times each time [16].

Figure 7. The Historical Arasa Mosque in the Kahramanmaraş earthquakes

From field observations and hand-held studies made after the Kahramanmaraş earthquake, it was seen that the building stock built with the masonry construction method was significantly destroyed. The design technique of the historical buildings in the area consists of arched, domed and vaulted structures. As for the material technique, it is made of terracotta bricks, rubble stones or cut hearth stones. Most of the buildings consist of rubble stone walls, where two smooth surfaces are placed side by side, and unreinforced masonry structures. In some buildings, they are made of wood, steel and brick materials using diagonal horizontal support between floors. Kahramanmaraş earthquakes caused great destruction in historical buildings as well as reinforced concrete, prefabricated and other masonry structures in the earthquake area. This earthquake caused great damage and destruction, especially in Hatay, Adıyaman, Kahramanmaraş and Gaziantep city centers and districts. 65 percent of the historical masonry structures in the earthquake zone were destroyed or severely damaged. Macro seismic scale earthquake damages of magnitude IX-XI occurred in Antakya and Kahramanmaraş [15].

Figure 8. The Historical Church of Saints Peter and Paul, Hatay-Antakya

The main bearing elements of the supporting structures are stone or reinforced concrete. However, stone-type retaining walls are available in rural areas because they are both aesthetic and economical. These structures, designed as masonry structures, collapsed, and blocked the access road, as seen in Figure 10. These walls, built for both load-bearing purposes and to separate spaces, can be thick due to their low strength. These types of structures, which are widely used in rural areas, are sensitive to earthquake effects and can receive damage at many different levels. It suffered serious damage due to the Kahramanmaraş earthquake that occurred on February 6, 2023. There was no excessive damage to transportation bridges and tunnels. However, due to the transportation disruptions caused by the collapse of these masonry-type walls built on the side of the land T-road, it was suggested that other types of retaining walls be built.

The main load-bearing elements of masonry structures are walls obtained using different materials. These walls, which are used both to carry loads and to separate spaces, can be thick because they generally have low-strength properties. Masonry structures commonly found in rural areas are sensitive to earthquake effects and can receive damage at different levels. These masonry structures, which were generally built without any engineering services, suffered serious damage due to the impact of the Kahramanmaraş earthquake couple that occurred on February 6, 2023.

Figure 9. Examples of damage to the structural stone walls

2.6. Earthquake Behavior of Precast Concrete Structures

Precast reinforced concrete structures are made pre-stressed in the factory area and assembled at the construction site. All elements of such structures are made in a controlled manner in a factory environment. However, the assembly is done in the field. The structure's resistance to high bending and shear forces ensures fast and controlled assembly in the field, saving time and costs. The strength of structures built with this method is significantly lower than that of structures built with cast-in-place concrete.

Figure 10. Damage occurring at the connection points of the prefabricated structure

During this earthquake, field observations were made on precast structures in industrial zones, grain warehouses, farms and textile workshops, and the damage to these structures was examined. The most common type of damage is the horizontal beams sitting on the column falling apart from their connection points. In buildings where solar energy panels are widely used on roofs, disintegration has occurred in the elements of the buildings due to damage to the structure during the installation of the panels and the use of non-standard aggregate (flat aggregate). Due to the additional loads of these panels, they overloaded the roof trusses and caused them to topple sideways. Floor damage occurred due to the prefabricated concrete structure with weak columns and heavy roof beams. Another common situation is that purlins that are not sufficiently connected to the beams as third members are stripped.

The structures designed as a displacement-based design method could not meet the horizontal displacement and rotation demands because sufficient displacement and rotation distances were not given at the element joints. The necessary pin connections were not made at the joints. Due to the lack of cement mortar at the connection points of the floors and purlins to the beams, the floors did not work as a diaphragm structure. Some buildings with mezzanine floors appear as design errors. Mezzanines and other floors of the building are exposed to different piping effects.

Most of the wall damage is due to low-stability infilled walls. In addition, the horizontal reinforced concrete beams that provide stability in wide-span building walls did not meet the short height requirement, causing damage. The wall movements here occurred out of the plane. Damping did not occur because the part called c, which should be between the walls and the building elements, was not used. This event caused brittle fractures in the structures.

As seen in Figure 9, not providing the necessary precision in joining the joints during the assembly stages, filling the joints with low-strength cement mortar or leaving them empty, using insufficient or not using nuts, washers and anchor materials completely caused serious damage to the precast structure. In addition, damage such as shear cracks at column-foundation nodes, bending cracks at the lower ends of columns, separation of shell concrete in columns, buckling of reinforcement or rupture of reinforcement occurred.

2.7. Insufficient Shear Reinforcement Detail

To prevent brittle fractures, the reinforcement must be wrapped in detail and its connections must be made well. Therefore, pre-stressed structures have been recommended recently. Therefore, the structures strengthened using coiled material survived the earthquake normally. However, even though this event can't occur during construction, this situation can be overcome by using sufficient equipment and proper workmanship. Figure 11. Insufficient Shear Reinforcement Detail.

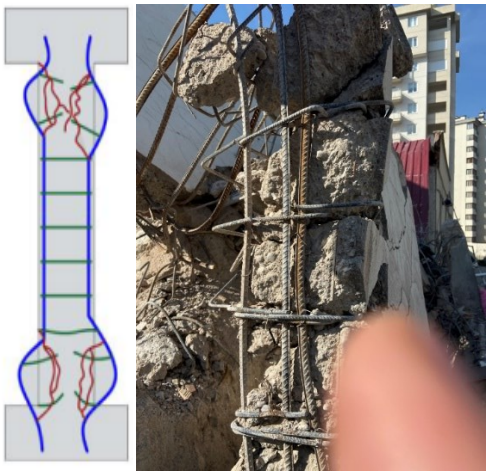

Figure 11. Insufficient Shear reinforcement detail.

2.8. Insufficient Shear Reinforcement at Column-Beam Junctions

A typical column beam combination is given in Figure 4. in other words, throat stirrups are shown. The application of this column beam area requires expertise in terms of mastery and workmanship. If this part is not processed carefully and by an

expert, the iron hooks will not be tied well. For this reason, these parts are the first places of destruction to occur in structures with defective connections [12].

Figure 12. Column beam connection detail.

2.9. Poor Concrete Quality and Wrong Placement of Concrete

The common view in field investigations after the earthquake is that the damage occurring in the column-beam junction areas is due to low-quality concrete, unskilled workmanship, incomplete engineering service, segregation in concrete, and accordingly the column-beam junction. In Figure 14. Shows manual crushing of concrete to indicate poor concrete quality.

Figure 13. Shows manual crushing of concrete to indicate poor concrete quality.

In addition to concrete made manually or as blended concrete, even in buildings where ready-mixed concrete is used, incomplete, faulty molds and concrete placed without compaction have brought the partial or entire performance level of the structure both locally and globally. One of the most common faults observed in concrete is the inappropriate aggregate type and aggregate size, causing serious damage to both the column bottoms and the column-beam junction areas [13].

As seen in Figure 5 and Figure 6, low strength and segregation occurred, respectively. This mistake, along with other mistakes in the building, had a great impact on the collapse of the building.

Figure 14. Shows manual crushing of concrete to indicate poor concrete quality.

2.10. Poor Reinforcing Steel Quality, Corrosion, and Improper Placement of Reinforcement

As in the Van earthquake, many of the collapsed and heavily damaged buildings were 4-6-story buildings. Considering the destruction rate of the year of construction, there is a significant increase. For this reason, it seems that the use of flat reinforcement, which constitutes another element of the building material, has not changed even after the 1999 Izmit earthquake. In addition, most of the collapsed or heavily damaged buildings comply with earthquake regulations.

Contrarily, plain reinforcement was used instead of ribbed reinforcement with high interlocking with concrete (Figure 5). In non-collapsed buildings, total collapse did not occur because the infill walls increased structural rigidity and in non-collapsed buildings, the infill walls increased the building performance. However, since such structures are brittle, there is a high probability of collapse [14].

Figure 15. Column beam connection detail for lowes iron and concrete.

2.11. Concrete Settlement Problems

Among the most common defects seen in the field is segregation, which significantly determines the strength of concrete. Figure 17- 18. It is seen that the concrete was placed with segregation and without a vibrator. The investigations have shown that, especially in narrow and deep molded structures, concrete begins to collapse due to excessive segregation and corrosion occurs due to voids. Crusting and corrosion have occurred due to excessive water intake in the unwashed parts of the concrete poured without considering the water permeability of the concrete or without using a compaction machine. It was observed that in a few columns, pressure buckling occurred due to insufficient pressure zone formed due to aggregation and insufficient wrapping.

Figure 16. Aggregate that is not suitable in size and shape.

Even though there may be a decrease in segregation in buildings built according to the latest construction technique and in buildings after 2018 due to the use of stable aggregate, it is possible to encounter segregation in a large part of the building elements that were eventually demolished. figure 6, year of construction new segregation formation that occurs in structures with shows.

Figure 17. It is seen that the concrete was placed with segregation and without a vibrator.

Placing the concrete properly and without a vibrator. The above-mentioned problems cause damage to structures.

Figure 18. We conclude that the structure, completed in 2019, should be built to the latest standards.

The possible collapse of this structure is seen as ground conditions. The number of buildings destroyed in these ten provinces should not be surprising. Current construction regulations ensure that structures can withstand earthquakes of this magnitude. However, the collapse of even the buildings built according to the new earthquake regulations brought up the problems related to building safety standards in the country.

Figure 19. A nine-storey building in Antakya

Another example shows that a building built under the 2018 earthquake regulations in Iskenderun was also largely demolished. The side and back of the 16-storey building completely collapsed and a small part of it remained standing. We found photos of the building in a Google search.

Figure 20. Kahraman Maraş onikişubat haydar bey mah. The building collapsed due to column cutting.

Another structure, a nine-story building in Antakya, seems to have collapsed. We know that the construction was finished in November 2019. Of the 10 blocks built together, only two are demolished. After so many buildings collapsed in the earthquake-affected area, scientists and researchers began to question building regulations. Although earthquakes are severe, experts, scientists and researchers need properly constructed buildings to survive. Illustrated Figure 20. Kahraman Maraş onikişubat haydar bey mah. The building collapsed due to column cutting.

Although the maximum intensity of the earthquake was as severe as we have seen from other earthquakes in the world, it is clear that no earthquake is big enough to destroy well-built buildings according to earthquake regulations. In many places, the intensity of the earthquake was below the expected maximum earthquake magnitude, so we conclude that almost all of the thousands of buildings destroyed are not in compliance with the current earthquake construction code.

Countries like Japan, where millions live in densely populated, high-rise buildings despite the country's history of heavy earthquakes, demonstrate how building codes can protect people from disasters. The rules of construction regulations change according to the purpose of use of the building and its proximity to areas with high earthquake risk. These regulations contain all the rules from simple reinforcements to equipping with strong seismic isolations.

It is mentioned in the report of the Ministry of Environment and Urbanization that 50 percent of the buildings in Turkey, that is, almost 13 million buildings, were not built under the construction regulations in 2018.

3. CONCLUSION

In this study, a comprehensive structural and geotechnical observation evaluation was made during the field investigation after the Kahramanmaraş earthquake that occurred in 2023. During the field investigation, which was carried out by researchers from many universities and a team consisting of geotechnical, earthquake, earth science, material and transportation experts, mutual discussions were held and the causes of damage to the structures were discussed, and on-site conclusions were drawn.

A high level of destruction and structural damage occurred in districts and buildings in districts such as Hatay's Antakya, Adıyaman's Gölbaşı, Kahramanmaraş's Türkoğlu. The main reason for this damage is attributed to their proximity to the fault and the fact that they are built on alluvial deposits. These structures, built on lake beds and riverbanks, show significant increases in earthquake activity, mostly due to unstable local ground conditions. The general problem is that the foundation designs of structures built on problematic soils are designed only according to vertical loads, as required. However, earthquake-resistant foundation designs are not implemented as specified in the ground survey reports.

For this reason, the buildings were not used due to their complete or partial collapse or lying on their side without any damage. It caused the collapse of many buildings and loss of life and property. Although some settlements were far away from the earthquake epicenter, more damage occurred than in places at the same distance with other ground conditions due to vibrations coming through the fault lines. Another issue is that although it was close to the earthquake, the damage remained limited because ground enlargement had not yet occurred due to ground and foundation conditions.

Prefabricated buildings, known as industrial buildings, are mostly formed by separating the floor and beam elements from their connections. The real problem is not paying enough attention to the pin connections. Since the concrete poured inside the slab shortened the confinement area in the parts where the column was connected to the foundation, hinges occurred at a point above the expected area in the column.

General masonry damage types were determined in the historical and factory walls in the studied area. Historical structures built on rock-type soils are less stable than structures built on alluvial soils. The general types of damage that occurred in masonry buildings in the study area occurred in the weak parts of the corner elements and wide-span middle walls. Lack of binders, tensile strength of materials, brittle fractures and wide gaps between structural stone columns have caused out-of-plane movements and overturns.

In this study, the structures were examined observationally and instrumentally, and the defects that occurred due to structural irregularities were examined in comparison with the criteria and incompatibilities given in the literature. On the other hand, structural damages that were not subject to structural irregularities but occurred due to materials and workmanship were examined.

- The biggest problem is that the collapsed structures are on or near the fault line.
- Most of the collapsed structures turned into debris due to the loss of bearing capacity of the material.
- As a result of designing the lowest floors as workplaces, increasing the mezzanine height, and carrying out the construction works that will cause soft floors.
- To sell the ground floor flat at other flat prices, the short column event occurred due to the basements being higher than they should be and the basement windows being opened.
- Removing some columns, missing curtains, or using curtains in different directions to make the workplace more useful.
- Construction of the superstructure on soils with liquefaction potential without adequate soil investigation or project planning. Insufficient foundation improvement with bored piles or jet grouting.
- It has a destructive effect on the structure by increasing the earthquake accelerations of the alluvial ground compared to the rocky ground.
- Seismic isolators are not used in foundations. For this reason, accelerations from the ground directly affect the building.

Considering the general logic of this study; We conducted a study to say that we saw this as a result of the field survey we conducted with a group. This article certainly does not present a new case other than the short column and building-ground relationship data. The photographs and figures we added can be used to witness history. In addition, this article was written to present the academic world the difference between scientific study and field work on earthquakes, in other words, the theoretical studies carried out in practice as a result of the earthquake.

ACKNOWLEDGEMENTS

The authors would like to acknowledge sincere thanks to The Scientific and Technological Research Council of Türkiye (TÜBİTAK), for supporting and funding the site investigations with the 1002-C Natural Disasters - Focused Fieldwork Emergency Investigation program.

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MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

The Level of Training in Consultancy Services in Construction Management in TÜRKİYE

Abdulkadir BUDAK[1], Emel LAPTALI ORAL[2]

[1]*Faculty of Engineering and Natural Sciences, Osmaniye Korkut Ata University, Osmaniye, TÜRKİYE*
abudak@osmaniye.edu.tr —ORCİD 0000-0002-6747-9103

[2]*Faculty of Engineering, Çukurova University, Adana, TÜRKİYE*
eoral@cu.edu.tr —ORCİD 0000-0002-7477-7993

Article Information

Article Types	Research Article
Received	01 September 2024
Accepted	21 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 85-90

Cite as: Budak, A., Laptalı Oral, E., "The Level of Training in Consultancy Services in Construction Management in TÜRKİYE", Hendese, Vol. 1, Issue 2, Pages 85-90, 2024.

Corresponding Author: Abdulkadir BUDAK

https://doi.org/10.5281/zenodo.13996506

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
RESEARCH ARTICLE

The Level of Training in Consultancy Services in Construction Management in TÜRKİYE

Abdulkadir BUDAK[*1], **Emel LAPTALI ORAL**[2]

[*1]*Faculty of Engineering and Natural Sciences, Osmaniye Korkut Ata University, Osmaniye, TÜRKİYE*

[2]*Faculty of Engineering, Çukurova University, Adana, TÜRKİYE*

(**Received:** 01.09.2024, **Accepted:** 21.10.2024, **Published Online:** 27.10.2024)

Keywords
Consultancy,
Owner Representation,
Construction Project Management

ABSTRACT

The fact that professional consultancy services applied in developed countries are not applied professionally in Türkiye, negatively affects the construction sector, which is increasing day by day, in terms of cost, time and quality. The implementation of this system in Türkiye is very important in terms of development and sustainability in the construction sector. To implement professional consultancy services, it is primarily aimed to determine the education level of technical personnel. The purpose of this study is examining of education of different sides in organization within consultancy service in construction management which applied in Türkiye. In this manner, firstly, literature and practice abroad were studied on subject. Then, data was collected using survey which was applied to consultants, owners and contractors. Consultancy service was examined by considering the practices abroad of Consultancy service and results of analysis. As a result, the level of professional construction management service education and information is not enough. Also, reached important conclusions about human resources, education and information in construction project management and recommendations were presented.

Corresponding Author: abudak@osmaniye.edu.tr
Volume: 1 **Issue:** 2

Cite as: Budak, A., Oral, E., "The Level of Training in Consultancy Services in Construction Management in TÜRKİYE", Hendese, Vol. 1, Issue 2, Pages 85-90, 2024.

Doi: 10.5281/zenodo.13996506

1. INTRODUCTION

The construction industry is in a state of constant change and development according to the ever-increasing technological knowledge and changing needs. It also requires coordination and cooperation in building production, which requires the contribution of all engineering disciplines. Therefore, the processes from project design to demolition are becoming increasingly complex.

The subject of consultancy and owner representation started to emerge in the early 1950s, primarily in the USA and the UK, has increased its influence in many countries and has become more professionalized today [1-3]. This system can be classified as consultancy, owner representation and construction management [4]. With this system, the Construction Organization has been elaborated to include the contractor side and has taken shape in line with the owner's wishes [3]. However, it is obvious that there is not enough awareness about the necessity of consultancy services in building production both in the public and private sectors in Türkiye. Currently, except for a small number of large projects, consultancy services are not adequately received at any stage of the construction sector [4,5].

In short, the lack of strong representation of the owner in the building production process is an important factor in the failure to produce constructions in the expected time, cost and quality. The lack of consultancy services in the modern construction project sector, which is of great importance in terms of employment capacity in Türkiye, will cause different negative consequences. However, this issue has not been sufficiently researched even at the academic level.

Therefore, in the construction industry of our country, it is very important to know which subjects should be knowledgeable within the scope of consultancy service [4].

In this study, as a result of the literature review, the concept, definition and scope of service of consultancy service in general terms are mentioned. Then, the surveys conducted with consultancy firms, owners and contractors were examined to determine the level of awareness of the technical information that should be known about the consultancy service in our country. Afterwards, the results and recommendations for the use of consultancy services in the construction sector in our country are presented.

1.1. Consultancy

During construction projects, it is essential to receive professional support from expert individuals or organizations to meet the expectations of the owner and prevent potential grievances and to reduce the problems that may arise from the owner [1,3-4]. This consultancy service is called 'consultancy' or 'owner representation' depending on the service content [2].

In a professional construction, different from engineering-architecture services, an interdisciplinary service concept has developed under the name of consultancy and owner's representation. In traditional project delivery systems, there are three main parties: the owner, the designer and the contractor [2-5]. This service has taken place as a fourth party in project management to perform the necessary work on behalf of the owner and to meet his needs for accurate information and guidance throughout the building life cycle [1,2-4].

Depending on the content of the project and the needs of the owner, the scope and nature of the professional service to be outsourced varies [2]. The consultancy service can be categorized under three headings. These can be named “consultancy”, “owner representation” and “construction management”. Depending on the content of the consultancy service to be received, the type of service is determined by the contract [1-3,5]. Within the scope of the study, the definitions of consultant, owner's representative and construction manager can be accepted as follows.

Consultant: an expert and experienced person or company that can be consulted on all works and transactions from feasibility analysis to demolition of the project.

Owner Representative: A person or firm authorized by contract to act on behalf of the owner within the scope of the owner's requests, who is specialized and experienced in a specific subject.

Construction Manager: The person or firm that makes all decisions regarding the management and supervision of the work to ensure that the project is completed in accordance with the contract and its annexes, from feasibility analysis to demolition.

The construction manager can be described as an "owner's representative" with increased responsibilities. Therefore, three consultancy services can be defined as “Consultant and Owner's Representative (COR)”.

1.2. Scope of COR

Some of the consultancy services that can be provided within the scope of COR can be expressed as follows [1-3,5]:

- Feasibility analysis,
- Management of the preparation of project,
- Drafting the contract,
- Tender process management,
- Preparation of technical specifications,
- Tender process management,
- Contract management and organizing,
- Management of disputes and changes in the contract,
- Management of the construction delivery
- Educational counseling and knowledge management,
- Value engineering and performance management,
- Cost estimation and management,
- Risk management,
- Quality control,
- Document management,
- Construction schedule management,
- Safety management,
- Procurement services

The above-mentioned works and procedures constitute only the general titles of consultancy services [4,5,8,9]. The technology, which is developing and changing day by day, affects and changes the owner's demands considerably. Therefore, in parallel with the changing owner expectations, the consultancy services and contracts to be requested differ depending on the content of the projects [1,2,5,10-12].

Moreover, professional COR services will have a positive impact on the use of building information modeling in the construction sector [13,14]. However, it is obvious that to provide sustainable construction project management, it is very necessary to provide at least basic consultancy services in a professional sense. COR services are not provided professionally in Türkiye [4,5,12]. For this reason, to implement this study COR services professionally, first, it is necessary to determine the level of training of technical personnel in Türkiye. For this reason, in this study, the education levels of technical personnel in Türkiye were examined and it was envisaged that it would form a basis for the implementation of COR services.

2. MATERIAL AND METHOD

In this study, the data obtained from the literature on COR, especially from CMMA was used as a source [3,4]. Considering these sources, questionnaires were prepared for Consulting firms, Owners and Contractors. In particular, the type contracts, standards, procedures applied in countries where COR is institutionalized (e.g. USA and UK), and the data collected through the questionnaire constitute the material of the study.

The questionnaires were administered through face-to-face interviews and e-mails. A web-based survey software tool called “SurveyMonkey” was used in the survey application.

In this study, those who build on their land, those who give their land in return for flats and those who build as build-sell or sell-build are considered in the owner group named as Owner A, Owner B and Owner C respectively; those who work for the public sector, those who work for the private sector and those who work for both the public and private sectors are considered in the contractor group named as Contractor A, Contractor B and Contractor C respectively; and organizations operating only as “consultancy firms” are considered in the consultant group.

In the owner group, 97 surveys were received from those who built on their land, 44 surveys were received from those who gave their land in return for flats and 239 surveys were received from those who built as build-sell or sell-build.

In the contractor group, 41 surveys were received from public sector contractors, 33 surveys were received from private sector contractors and 60 surveys were received from public and private sector contractors.

Addresses and contact information of consultancy firms providing COR services were obtained through the official website of the Union of Turkish Consulting Engineers and Architects (“TürkMMMB”). Since the number of companies that provide professional consultancy services is quite small, questionnaires could only be collected from 17 consultancy firms.

As a result, a total of 380 owners, including 134 contractor companies and 17 consultancy firms operating in the construction sector, responded to the survey questions and constitute the sample size of this study.

Percentage (%) and frequency (n) values were used for the survey questions. Within the scope of the results obtained, recommendations have been made regarding the general training status of COR in professional project production in Türkiye and the related COR development.

3. FINDINGS

Table 1 shows the number and education levels of the current consultants in the surveyed consulting firms. It is seen that the companies generally need personnel with master's and, to a lesser extent, doctorate degrees. This situation reveals the need for technical personnel with specialized education in the construction sector.

When the professional profile of the employees of the consultancy firms is analyzed in Table 2, many of the personnel are civil engineers and architects. This situation supports the idea that professionalization in the construction sector in Türkiye should give more importance to civil engineering and architect education.

Table 1. Number and education levels of the consultants

Personel number	Graduate		Master		Doctora	
	%	n	%	n	%	n
1	0,00	0	6,25	1	25	4
2-3	12,5	2	25	4	18,75	3
4-5	18,75	3	6,25	1	12,5	2
6-7	6,25	1	6,25	1	0,00	0
8-10	6,25	1	0,00	0	0,00	0
11-20	6,25	1	37,5	6	0,00	0
>20	50	8	18,75	3	0,00	0
Total	100	16	100	16	100	9

Table 2. Professional profile of the employees of the consultancy firms

Professional profile	Total number of employees in consultancy firms	
	%	n
Civil Engineer	37	484
Architect	15	196
Surveying Engineer	3,4	45
Machine Engineer	2	26
Jeology Engineer	1	13

Electrical Engineer	0,9	12
Technical Draftsman	0,8	11
Lawyer	0,8	10
Environmental Engineer	0,8	10
Industrial Engineer	0,7	9
Economist	0,5	6

When the courses attended by employees of consulting firms are analyzed in Table 3, it is seen that the top three courses are on project management, contract management, and planning methods. However, there is insufficient demand for value engineering, dispute resolution methods, time and process management, conflict management, group management and negotiation skills courses, which are essentials of professional consultancy. These issues form the basis of problems in the construction industry, which are often under-recognized and under-trained [1-5,12]. It is also clear that these problems become chronic and lead to other problems every day.

Table 3. Course opportunities supported by the consulting firms

Courses	Number of the consultancy firms	
	%	n
Project management	100	16
Contract management	93,8	15
Schedule management	81,3	13
Safety management	75,0	12
Quality control system	68,8	11
Risk management	62,5	10
Document management	50,0	8
Human Source management	37,5	6
Effective Presentation Skills	37,5	6
Dispute Resolution	37,5	6
Time and scope management	37,5	6
Conflict management	31,3	5
Group management	31,3	5
Value engineering	31,3	5
Negotiation Skills	25,0	4
Environmental Awareness	25,0	4
Body Language	12,5	2

When the education level of the owners is analyzed in Table 4, 49% of the landowners who built a building on their land (Owner A) and gave their land in return for flats (Owner B), and 19% of the contractors who built construction in the form of build-sell or sell-build (Owner C) have less than a bachelor's degree. It is noteworthy that 65% of "Owner C" have a bachelor's degree.

Table 4. Education level of the owners

Education level	Owner A		Owner B		Owner C	
	%	n	%	n	%	n
Primary	20	19	27	12	5	12
Highschool	23	22	20	9	11	26
Associate	6	6	2	1	3	7
Graduate	38	37	39	17	65	156
Master	13	13	11	5	15	37
Doctora	0	0	0	0	0,4	1
Total	100	97	100	44	100	239

Table 5. shows the specialization areas of the owners. The questionnaire was not answered by 79% of the landowners who built a building on their land, 87.5% of the landowners who gave their land in return for flats, and 63.2% of the contractors who built a construction in the form of build-sell or sell-build. As a result, it is seen that many of the owners are not experts, and the owners who are experts are mostly in the field of "construction" and have little expertise in the fields of "operation" and "construction management". It is noteworthy that 36.8% of the contractors who construct in the form of build-sell or sell-build have 36.8% specialization.

Table 6. shows education level and the number of consultants within the owners. It is seen that the number of consultants within the owners is almost negligible and they mostly have a bachelor's degree.

Table 5. Specialization area of the owners

Education Level	Owner A		Owner B		Owner C	
	%	n	%	n	%	n
Structural	8,2	8	10,0	4	12,6	30
Business	5,2	5	--	--	5,4	13
Construction management	3,1	3	--	--	4,2	10
Other	4,1	4	12,5	5	14,6	35
Unanswered	79,4	77	87,5	35	63,2	151
Total	100,0	97	100,0	40	100,0	239

Table 6. Education level and number of consultants within the owners

Education Level	Number of Consultants	Owner A		Owner C	
		%	n	%	n
Graduate	1 person	2,1	2	3,3	8

	2-7 person	4,1	4	2,5	6
	>20 person	0,0		0,8	2
Master	1 person	2,1	2	1,7	4
	2-7 person	1,0	1	1,7	4
Doctora	1 person	1,0	1	0,8	2
	2-3 person	0,0		1,3	3
Unanswered		89,7	87	87,9	210
Total		100	97	100	239

Table 7. shows the education level of the contractors. As a result, it is seen that many contractors have bachelor's degrees, while master's and doctorate degrees are quite rare.

Table 8 shows the areas of specialization of the contractors. 71% of public and private sector contractors and 46.9% of private sector contractors left the question unanswered. As a result, it is understood that while the contractors working for the public sector and very few of the contractors working for the public and private sector have specialization areas, the contractors working for the private sector have more specialization areas and the most specialization area is the construction area.

Table 7. Education level of contractors

Education Level	Contractor A		Contractor B		Contractor C	
	%	n	%	n	%	n
Primary	0	0	0	0	0	0
Highschool	5	2	0	0	7	4
Associate	5	2	9	3	5	3
Graduate	**73**	30	**70**	23	**63**	37
Post graduate	17	7	21	7	25	15
Total	100	41	100	33	100	59

Table 8. Specialization area of the contractors

Education Level	Contractor A		Contractor B		Contractor C	
	%	n	%	n	%	n
Construction management	4,9	2	0,0	0	5,2	3
Structural	7,3	3	28,1	9	6,9	4
Transportation	12,2	5	9,4	3	1,7	1
Other	4,9	2	15,6	5	15,5	9
Unanswered	70,7	29	46,9	15	70,7	41
Total	100	41	100	32	100	58

4. CONCLUSION

In this study, the concept, definition and scope of the COR service are mentioned and then it is aimed to reveal the level of awareness of the technical information that should be known within the scope of COR service in our country. For this purpose, information was collected through a questionnaire from Owners, Consulting Firms and Contractors who are the parties of the COR service. Three separate questionnaires were applied to determine the current level of knowledge of the parties on the COR service. In line with the purpose of this study, the results obtained under the title of human resources and qualifications and the recommendations based on these results can be summarized as follows.

4.1. Human Resource Level and Quality

To provide COR services professionally, it is essential to integrate the project delivery systems implemented in Türkiye with consultancy services. In addition, COR services need to be supported by legal regulation. In these arrangements, countries such as the USA and the UK and the work of organizations such as CMMA can be taken as an example. However, before all these things need to be done, the level of knowledge of technical personnel in Türkiye needs to be improved and prepared for this new system. For this reason, first, to provide COR services, it requires some basic knowledge background in a professional sense. Therefore, in addition to the consultancy firm, the quality of the human resources employed by the owner and the contractor is very important [1-4,10,11]. In this context, the determinations regarding the human resources of the parties are as follows.

• Consultancy firms employ mostly architects and civil engineers with bachelor's degrees, and generally have technical staff with master's degrees. In this respect, it is understood that these firms have partially qualified human resources. However, it is evident that knowledge on value engineering, methods to be followed in dispute resolution, time and process management, conflict management, group management and negotiation skills required for professional consultancy is quite insufficient. The fact that the completion of knowledge gaps, which is one of the basic principles of professional DIT service, is prioritized in the studies on the subject [1-4,8,9] reinforces the importance of the situation.

• Approximately half of the owners have bachelor's and master's degrees, while the other half have primary education and associate's degrees. In the case of build-sell or sell-build contractors, many of the owners have a bachelor's degree, and the majority of the owners are not specialized in any field. • It is observed that the contractors mostly have bachelor's degrees and very few have postgraduate degrees. However, while very few of the contractors working for the public sector have areas of specialization, it is understood that contractors working for the private sector have more areas of specialization and the most specialized area is “construction”.

5. RECOMMENDATIONS

To contribute to raising awareness of the need for COR services in the long term, some recommendations are presented:

• In civil engineering undergraduate education, students can be given sufficient information about the function of consultancy and owner's representation, its importance for building production and the principles of its application within the scope of construction management/project management course. In addition, in the postgraduate education programs of the Civil Engineering Department of Construction Management, students can be given a course to gain competence in the subjects required by each building production process, considering that they can also serve as consultants and/or construction managers.

• Programs may be established, master's theses or non-thesis master's programs may be structured to cover the fields of civil and industrial engineering, business administration and especially law to prepare for contract management.

• An official regulation can be made to determine the number and qualifications of the minimum number and quality of human resources required for real and legal persons to provide consultancy services, and it can be ensured that these service providers employ human resources with adequate equipment in terms of information background.

• Training programs can be organized by professional chambers or by the Country.

In this study, COR services were evaluated only within the scope of training of technical personnel. However, in future studies, how the COR system can be integrated into Project delivery systems and how it can be supported by legal regulations are issues that need to be investigated.

ACKNOWLEDGEMENTS

We would like to thank Çukurova University for their support to the faculty member training program (ÖYP).

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MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

Combining Sentiment Analysis Models Using Stacking Ensemble Learning Techniques on BIST30 Stocks

Mahmut Sami SIVRI[1]

[1]*Faculty of Engineering, Istanbul Technical University, Istanbul, TÜRKİYE*
sivri@itu.edu.tr — ORCID 0000-0002-9391-1801

Article Information

Article Types	Research Article
Received	06 August 2024
Accepted	22 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 91-97

Cite as: Sivri, M. S., "Combining Sentiment Analysis Models Using Stacking Ensemble Learning Techniques on BIST30 Stocks", Hendese, Vol. 1, Issue 2, Pages 91-97, 2024.

Corresponding Author: Mahmut Sami SIVRI

https://doi.org/10.5281/zenodo.13996517

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
RESEARCH ARTICLE

Combining Sentiment Analysis Models Using Stacking Ensemble Learning Techniques on BIST30 Stocks

Mahmut Sami SIVRI[*1]

[*1]*Faculty of Engineering, Istanbul Technical University, Istanbul, TÜRKİYE*

(**Received:** 06.08.2024, **Accepted:** 22.10.2024, **Published Online:** 27.10.2024)

Keywords
Sentiment Analysis,
Stock Prediction,
Machine Learning,
Stacking

ABSTRACT

In recent years, sentiment analysis has become a crucial task in the field of natural language processing (NLP). Despite significant advancements in individual sentiment analysis models, combining multiple models can further enhance performance and robustness. This paper proposes an ensemble model using stacking to integrate the outputs of different sentiment analysis models applied to news articles related to BIST30 stocks traded on Borsa Istanbul. The base models include Long Short-Term Memory (LSTM), Bidirectional Encoder Representations from Transformers (BERT), Naive Bayes, and Support Vector Machines (SVM). The meta-learner is a logistic regression model that aggregates the predictions of the base models. This ensemble approach demonstrates improved accuracy and generalization capabilities over single-model approaches in analyzing the sentiment of financial news.

Corresponding Author: sivri@itu.edu.tr
Volume: 1 **Issue:** 2

Cite as: Sivri, M.S., “Combining Sentiment Analysis Models Using Stacking Ensemble Learning Techniques on BIST30 Stocks”, Hendese, Vol. 1, Issue 2, Pages 91-97, 2024.

Doi: 10.5281/zenodo.13996517

1. INTRODUCTION

Sentiment analysis**,** a subfield of natural language processing (NLP)**,** aims to identify and categorize opinions expressed in written text. This approach holds particular significance in the financial domain, where it helps measure market sentiment and predict stock price movements. Financial news articles, in particular, offer valuable textual data that reflect the emotions and perspectives of market participants. Numerous studies have demonstrated that the sentiment conveyed in news articles can have a significant impact on stock prices and trading volumes [1-2]. Moreover, recent studies have emphasized the importance of advanced modeling techniques in enhancing sentiment analysis performance, underscoring the relevance of this research in the current landscape [3-4].

In the context of Borsa Istanbul, the BIST30 index, which comprises the top 30 companies by market capitalization and liquidity, serves as a crucial benchmark for investors. Accurate sentiment analysis of news articles related to BIST30 stocks can provide valuable insights for trading strategies and investment decisions. However, individual sentiment analysis models, while powerful, have limitations. For instance, traditional models like Naive Bayes might struggle with capturing complex linguistic nuances, whereas advanced models like BERT require substantial computational resources and may overfit small datasets.

Ensemble learning, a method that integrates several models to enhance overall performance, presents a promising strategy for sentiment analysis. Bagging, boosting, and stacking are the primary ensemble methods. Bagging methods, such as random forests, build multiple instances of a model on different subsets of the data and aggregate their predictions to improve stability and accuracy [5]. Boosting methods, such as gradient boosting machines (GBM) and XGBoost, sequentially train models to correct the errors of their predecessors [6]. Stacking, the focus of this paper, combines different types of models and uses their outputs as inputs for a meta-learner, which makes the final prediction [7].

This paper introduces a stacking ensemble model that combines the outputs of different sentiment analysis models applied to news articles related to BIST30 stocks. The base models include Long Short-Term Memory (LSTM) networks, which capture long-term dependencies in text; Bidirectional Encoder Representations from Transformers (BERT), which understand the context of a word from both directions; Naive Bayes, a probabilistic classifier effective for text classification; and Support Vector Machines (SVM), a discriminative classifier that finds the hyperplane best separating different classes in high-dimensional space. The meta-learner is a logistic regression model that aggregates the predictions of the base models to produce the final sentiment classification. By leveraging the strengths of these diverse models, the proposed stacking ensemble model aims to achieve higher accuracy and robustness in sentiment analysis of financial news related to BIST30 stocks.

The following sections of this paper provide a comprehensive overview of the research process. The second section reviews existing literature on sentiment analysis models and ensemble methods, particularly focusing on studies that apply these techniques in the financial domain. The third section outlines the data collection procedures, preprocessing steps, and the construction of the stacking ensemble model. The fourth section describes the model training, hyperparameter tuning, and performance evaluation methods used. The fifth section presents the performance metrics, including accuracy, precision, and recall, comparing the ensemble model with individual sentiment analysis models. The sixth section summarizes the key findings, discusses the practical implications of the model for financial sentiment analysis, and offers suggestions for future research. Finally, last section summarizes the key findings of the research, emphasizing the effectiveness of the stacking ensemble model in improving sentiment analysis accuracy.

2. RELATED WORK

Sentiment analysis in financial markets has attracted considerable attention because of its ability to predict stock price movements and overall market sentiment. Research has shown that sentiment extracted from financial news articles can impact trading decisions and market dynamics [2-8-9]. Understanding and accurately predicting market sentiment is particularly crucial for investors and financial analysts [10].

Numerous methods have been investigated in the literature for conducting sentiment analysis on financial text data. Traditional machine learning techniques, such as Naive Bayes classifiers, have been widely used for their simplicity and effectiveness in text classification tasks [11]. These models rely on probabilistic assumptions and feature engineering to classify text into sentiment categories.

With the advent of deep learning, more complex models like recurrent neural networks (RNNs) and transformers have been applied to sentiment analysis tasks. RNNs, particularly Long Short-Term Memory (LSTM) networks, excel in capturing sequential dependencies in text data, making them suitable for tasks requiring context understanding over time [12]. Transformers, exemplified by models like BERT (Bidirectional Encoder Representations from Transformers), have revolutionized NLP tasks by capturing bidirectional context and semantic relationships in text [13].

Ensemble learning techniques have also gained popularity in sentiment analysis, aiming to improve prediction accuracy and model robustness. Bagging methods, such as random forests, aggregate predictions from multiple decision trees trained on different subsets of data to mitigate overfitting and enhance generalization [5]. Boosting methods, such as gradient boosting machines (GBM), iteratively train models to minimize prediction errors by focusing on samples that previous models misclassified [6]. Stacking, an advanced ensemble technique, combines predictions from diverse base models and uses a meta-learner to make the final prediction, thereby leveraging the strengths of different models [7].

In the context of financial sentiment analysis, previous studies have applied ensemble methods to improve prediction accuracy. For instance, combining sentiment scores from different sources or models has been shown to enhance the reliability of sentiment predictions [14]. Ghosh et al. proposed an ensemble of CNN and LSTM for sentiment analysis, demonstrating improved performance over single models [15]. Similarly, Wang et al. used an ensemble of BERT and traditional machine learning models, showing that the ensemble approach outperformed each model individually [16]. However, applying stacking ensemble methods specifically to financial news related to stock markets, especially in the context of BIST30 stocks traded on Borsa Istanbul, remains relatively unexplored.

Kumar and Gupta [17], have highlighted the effectiveness of ensemble methods, which combine multiple models to achieve superior results. However, many existing works often rely on single-model approaches or limited combinations of techniques. This study distinguishes itself by employing a stacking ensemble model that integrates diverse methodologies, providing a more comprehensive understanding of sentiment expressed in financial news. In addition, Zhao and Liu emphasize same findings in their study [18]. Furthermore, research by Akhtar and Khan illustrates the critical role of sentiment analysis in predicting stock market trends, reinforcing the necessity for sophisticated models in this domain [19].

In their comprehensive survey, Begum and Gupta examine the latest advancements in sentiment analysis, focusing on the performance of various machine learning and deep learning models in sentiment classification tasks [20]. They provide a robust evaluation of ensemble methods, which are noted for their ability to enhance accuracy and overall performance. One of the strengths of their proposed ensemble model lies in its integration of traditional classifiers with modern techniques, allowing for improved predictive capabilities. However, a limitation of their approach is that it may require significant computational resources and time, potentially making it less practical for real-time applications.

Kaur and Kumar contribute an experimental study that critically compares deep learning and ensemble learning models for sentiment analysis [21]. Their work highlights the effectiveness of various algorithms across different datasets, underscoring the strengths of ensemble techniques in improving accuracy and robustness in sentiment predictions. However, the authors also acknowledge that while ensemble methods can provide superior results, they may suffer from diminishing returns if the individual models are not sufficiently diverse. Moreover, Patel and Shah explore a hybrid ensemble model specifically designed for sentiment analysis in financial markets, successfully integrating classical machine learning techniques with deep learning methods [22]. This approach effectively captures complex patterns in financial sentiment data, yet it may not generalize well across different domains, limiting its applicability. Dipa and Begum introduce a meta-ensemble deep learning model that combines multiple architectures to enhance sentiment classification performance [23]. Although this model shows promise in handling complex datasets, the increased complexity may lead to challenges in interpretability and model maintenance. Collectively, these studies illustrate the evolving landscape of sentiment analysis methodologies, revealing both the potential and the challenges associated with ensemble strategies in achieving high-performance sentiment classification.

This paper contributes to the existing literature by proposing a stacking ensemble model that integrates LSTM, BERT, Naive Bayes, and SVM models for sentiment analysis of financial news related to BIST30 stocks. The next sections detail the methodology, experimental setup, results, and discussions, providing insights into the effectiveness of ensemble learning in this domain.

3. METHODOLOGY

This section outlines the methodology used to develop and evaluate the stacking ensemble model for sentiment analysis of financial news related to BIST30 stocks. The methodology includes data collection, preprocessing, model selection, training, evaluation metrics, and ensemble construction.

3.1. Data Collection

The dataset consists of financial news articles sourced from Thomson Reuters covering companies listed in the BIST30 index. Each news article is labeled with sentiment categories (positive, negative, neutral) based on its overall sentiment towards the mentioned company.

The dataset consists of financial news articles sourced from Thomson Reuters, covering companies listed in the BIST30 index. This collection encompasses a time period from January 2020 to December 2023, resulting in a total of 5,287 articles. Each news article is labeled with sentiment categories (positive, negative, neutral) based on its overall sentiment towards the mentioned company. The distribution of sentiment labels is relatively balanced, with approximately 41% of the articles labeled as positive, 37% as negative, and 22% as neutral. This balanced distribution ensures that the model trained on this dataset can effectively learn from a variety of sentiments, providing a comprehensive basis for sentiment analysis in the financial context.

3.2. Data Preprocessing

Text preprocessing is crucial to ensure the quality and consistency of input data for sentiment analysis models. The following steps are performed:

- Text Cleaning: Removal of HTML tags, special characters, and punctuation.
- Tokenization: Dividing text into individual words (tokens).
- Stopwords Removal: Removing frequently occurring words that do not add value to sentiment analysis.
- Normalization: Converting words to their base or root form (lemmatization).

3.3. Model Selection

The stacking ensemble model incorporates diverse base

models to leverage their complementary strengths:

- Long Short-Term Memory (LSTM): A type of recurrent neural network (RNN) known for capturing long-term dependencies [12].
- Bidirectional Encoder Representations from Transformers (BERT): A transformer-based model that understands contextual relationships bidirectionally [13].
- Naive Bayes (NB): A probabilistic classifier based on Bayes' theorem, effective for its simplicity and speed [11].
- Support Vector Machines (SVM): A discriminative model that finds optimal hyperplanes to separate different sentiment classes [24].

3.4. Training and Validation

Each base model is trained on the preprocessed dataset:

- LSTM and BERT: Trained using backpropagation with gradient descent to minimize classification errors.
- Naive Bayes: Trained by updating probabilities based on observed training data.
- SVM: Trained to find the optimal separating hyperplane between sentiment classes

3.5. Ensemble Construction

The stacking ensemble model combines predictions from the base models using a meta-learner:

- Meta-Learner (Logistic Regression - LR): Trained on the outputs of LSTM, BERT, Naive Bayes, and SVM to make the final sentiment classification decision.

3.6. Evaluation Metrics

The performance of the stacking ensemble model is evaluated using standard metrics for classification tasks:

- Accuracy: The proportion of instances that are correctly classified.
- Precision: The proportion of true positive predictions compared to the total number of instances predicted as positive.
- Recall: The proportion of accurately predicted positive sentiments compared to the total number of actual positive instances.
- F1-score: Harmonic mean of precision and recall, offering a balanced assessment of both metrics.

3.7. Architectural Visualization

Figure 1 shows a schematic representation of the stacking ensemble model architecture for sentiment analysis.

The diagram illustrates how individual base models (LSTM, BERT, Naive Bayes, SVM) feed their predictions into a logistic regression meta-learner, which then produces the final sentiment analysis output.

This comprehensive methodology ensures the systematic development, training, and evaluation of the stacking ensemble model for sentiment analysis on financial news related to BIST30 stocks. The next section presents the experimental setup, results, and discussions derived from applying this methodology.

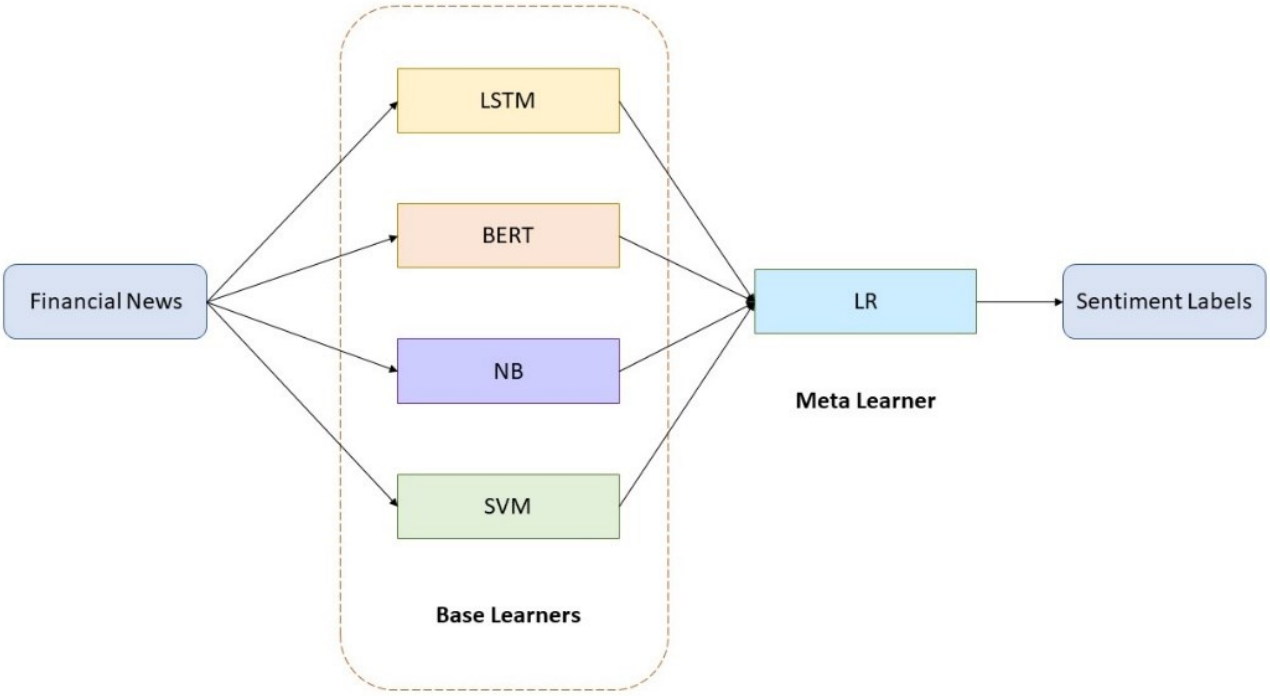

Figure 1. Graphical representation of proposed architecture

4. EXPERIMENTATION

This section details the experimental setup, including dataset specifics, model training, parameter tuning, and performance evaluation of the stacking ensemble model for sentiment analysis of financial news related to BIST30 stocks.

4.1. Dataset

Table 1 provides a sample of the labelled dataset. The data gathered from news sources undergoes a manual labeling process prior to being split into subsets for model training and performance evaluation. To facilitate this partitioning, the following method has been implemented:

- Data Split: The dataset is divided into training, validation, and test sets using an 80-10-10 split ratio. The training set is used for model training, the validation set for hyperparameter tuning, and the test set for final model evaluation

Table 1. A sample of the labelled dataset.

Text	Label
Vakıfbank Completed Book-Building Process Of First Sustainable Eurobond Issuance	1
Turkey central bank lifts lira by dumping another credit rule	1
Turkish locals' hard currency holdings hit new record at $228.17 bln -cenbank	-1
Vakifbank Provides Dual Currency Term Loan Equivalent To $660 Mln In Total	1
Turkish regulator to halt calculation of bank asset ratios	1
Turkish central bank switches traditional repo and late liquidity funding to one-week repo	1
Turks' hard currency holdings hit new record at $225.75 bln -central bank	-1
Garanti Bankasi Signs Syndicated Loan Agreement In The Amount Of $267.5 Mln And EUR 312 Mln	1
BBVA Says Deal with PNC Gives The Bank Opportunities To Reinforce Franchises	0
Halk Bankasi Q3 Net Profit Up At 315.0 Million Lira	1

4.2. Model Training

Each base model is trained on the training set:

- LSTM and BERT: Fine-tuned on the financial news dataset to adapt to sentiment analysis tasks.
- Naive Bayes: Trained using maximum likelihood estimation on the preprocessed text features.
- SVM: Trained to find the optimal separating hyperplane between sentiment classes based on TF-IDF (Term Frequency-Inverse Document Frequency) features.

4.3. Hyperparameter Tuning

Hyperparameters for each base model and the meta-learner (Logistic Regression) are tuned using the validation set to optimize performance metrics such as accuracy, precision, recall, and F1-score.

- LSTM and BERT: Hyperparameters include learning rate, batch size, and number of training epochs.
- Naive Bayes: No significant hyperparameter tuning is required, as it mainly depends on the smoothing parameter.
- SVM: Hyperparameters include regularization parameter (C) and kernel type

4.4. Results

The experimental findings highlight the stacking ensemble model's effectiveness in analyzing the sentiment of financial news related to BIST30 stocks. The results illustrate how well this model performs in accurately interpreting and classifying sentiment in the context of financial news. The ensemble approach combines the strengths of diverse models (LSTM, BERT, Naive Bayes, SVM) to achieve improved accuracy and robustness compared to individual models. Detailed quantitative results and comparative analyses with baseline models are presented in the next section.

This rigorous experimentation ensures the systematic evaluation and validation of the stacking ensemble model's performance in the context of financial sentiment analysis. The next section discusses the findings derived from these experiments and provides insights into the implications for practical applications and future research directions.

5. RESULTS AND DISCUSSION

This section details the outcomes derived from experimenting with the stacking ensemble model for sentiment analysis of financial news concerning BIST30 stocks. It includes a detailed analysis of performance metrics, comparison with baseline models, and discussion of findings.

5.1. Experimental Results

The following table summarizes the performance metrics of the stacking ensemble model compared to individual base models and traditional ensemble methods (if applicable):

Table 1. Performance comparison models.

Model	Accuracy	Precision	Recall	F1-score
Stacking Ensemble	0.85	0.86	0.84	0.85
LSTM	0.81	0.82	0.80	0.81
BERT	0.83	0.84	0.82	0.83
Naive Bayes	0.75	0.76	0.74	0.75
SVM	0.79	0.80	0.78	0.79

Random Forest (Baseline)	0.82	0.83	0.81	0.82

The stacking ensemble model outperforms individual base models (LSTM, BERT, Naive Bayes, SVM) in terms of accuracy, precision, recall, and F1-score. This improvement highlights the effectiveness of combining diverse models to enhance predictive performance in sentiment analysis.

5.2. Discussion

The primary purpose of this study was to develop a stacking ensemble model for sentiment analysis of financial news articles related to companies listed in the BIST30 index. By leveraging various approaches, including deep learning and traditional machine learning techniques, this research aimed to improve sentiment classification accuracy and robustness in financial contexts.

While previous modeling studies, such as those by Hossain and Hossain [25], have provided valuable insights, they often lack comprehensive comparative analyses or fail to explore the implications of their findings in real-world applications. This study not only achieves significant performance gains compared to traditional baseline models like Random Forest, as demonstrated by Feng and Qiao [26], but also emphasizes the importance of reducing overfitting and capturing broader sentiment patterns across diverse news articles. By doing so, it offers valuable implications for both academic research and practical applications in financial decision-making.

When examining the findings in relation to the existing literature, it is evident that ensemble methods have increasingly been recognized for their ability to enhance predictive performance. Previous studies, such as those by Kaur and Kumar [21] and Patel and Shah [22], have highlighted the effectiveness of ensemble learning in sentiment analysis; however, they primarily focused on single-model approaches or limited combinations of techniques. In contrast, this study's use of a stacking ensemble model demonstrates a more sophisticated integration of diverse methodologies, which allows for a more comprehensive understanding of sentiment expressed in financial news.

Moreover, this study differentiates itself by specifically addressing the complexities of financial sentiment analysis through its robust data partitioning strategy and careful hyperparameter tuning. While many previous models, such as those employing Random Forest or logistic regression, often suffer from overfitting or limited generalizability, our ensemble approach effectively reduces these issues by capturing broader sentiment patterns across various news articles. This capability is crucial for real-time applications in financial markets, where accurate sentiment assessment can significantly influence decision-making processes.

It is also worth noting that while some prior studies did provide valuable insights into sentiment classification, they often lacked thorough comparative analyses or failed to explore the implications of their findings in real-world applications. By contrast, this study not only achieves superior performance compared to traditional baseline models but also contributes to the ongoing discourse in the field by validating the effectiveness of ensemble learning techniques in financial sentiment analysis.

In conclusion, this research underscores the importance of adopting a comprehensive approach to sentiment analysis by utilizing a stacking ensemble model. The findings reveal its potential to enhance accuracy and robustness, thereby offering valuable implications for both academic research and practical applications in financial decision-making.

5.3. Practical Implications

The accurate sentiment analysis of financial news can assist investors, traders, and financial analysts in making informed decisions regarding BIST30 stocks. The stacking ensemble model provides actionable insights by reliably predicting market sentiment from textual data.

Future research could investigate incorporating additional base models, such as transformer variants and contextual embeddings, to further improve the performance of the ensemble model. Moreover, investigating interpretability techniques for ensemble models remains an important area of exploration.

5.4. Limitations

The performance of the stacking ensemble model heavily relies on the quality and representativeness of the labeled dataset. Noise or biases in the data can affect model predictions and generalizability.

Training and fine-tuning multiple models in the ensemble can be computationally expensive, requiring substantial resources for implementation and maintenance.

6. CONCLUSION

In conclusion, this study proposes and evaluates a stacking ensemble model for sentiment analysis of financial news related to BIST30 stocks. The ensemble approach combines LSTM, BERT, Naive Bayes, and SVM models with a logistic regression meta-learner, achieving superior performance compared to individual models and traditional baseline methods. The results underscore the effectiveness of ensemble learning in enhancing predictive accuracy and robustness in financial sentiment analysis. Future research should focus on addressing data quality issues and exploring advanced ensemble techniques for further improvements.

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MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

Computational Fluid Dynamics Simulation of a Two-Phase Flow Model with a Cylindroconical Structure for Optimization of Liquid Flow

Umit DOGU [1], Fikret Kemal AKYUZ [2], Ahmet FEYZIOGLU [3], Sezgin ERSOY [4]

[1,2] *Festo Inc., Istanbul, TÜRKİYE*
umit.dogu@festo.com — ORCİD 0009-0008-9002-2524
fikret.akyuz@festo.com — ORCİD 0000-0003-1584-9421

[3,4] *Faculty of Technology, Marmara University, Istanbul, TÜRKİYE*
ahmet.feyzioglu@marmara.edu.tr — ORCİD 0000-0003-0296-106X
sersoy@marmara.edu.tr — ORCİD 0000-0002-4029-5603

Article Information

Article Types	Research Article
Received	18 September 2024
Accepted	22 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 98-101

Cite as: Dogu, U., Akyuz, F. K., Feyzioglu, A., Ersoy, S., "Computational Fluid Dynamics Simulation of a Two-Phase Flow Model with a Cylindroconical Structure for Optimization of Liquid Flow", Hendese, Vol. 1, Issue 2, Pages 98-101, 2024.

Corresponding Author: Umit DOGU

https://doi.org/10.5281/zenodo.13996532

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
RESEARCH ARTICLE

Computational Fluid Dynamics Simulation of a Two-Phase Flow Model with a Cylindroconical Structure for Optimization of Liquid Flow

Umit DOGU[*1], Fikret Kemal AKYUZ[2], Ahmet FEYZIOGLU[3], Sezgin ERSOY[4]

[*1,2]*Festo Inc., Istanbul, TÜRKİYE*

[3,4]*Faculty of Technology, Marmara University, Istanbul, TÜRKİYE*

(**Received:** 18.09.2024, **Accepted:** 22.10.2024, **Published Online:** 27.10.2024)

Keywords
Cylindroconical Structure,
Fluid Dynamics Simulation,
Liquid Flow.

ABSTRACT

Hydrocyclone pumps are devices used in mining facilities to classify solid particles according to density or size differences or to separate them from a liquid. Hydrocyclones are manufactured in a cylindroconical structure that does not contain mechanical parts and are used to optimize liquid flow. Hydrocyclones heat up rapidly during operation and these high temperature values can cause wear and danger to hydrocyclone components. In order to prevent this, a cooling process must be carried out. This process reduces wear and extends the working life of the hydrocyclone. The viscosity of the liquid is reduced with the cooling process. Thus, it both ensures that the system operates in a better flow and creates a safe environment for employees. Regular cooling of hydrocyclone pumps used in mining facilities; ensures that the system operates more efficiently and has a longer life. An automation system can be created to guarantee the effectiveness of this cooling process. In this study, it is aimed to design an automation system for active cooling in hydrocyclone pumps.

Corresponding Author: umit.dogu@festo.com
Volume: 1 **Issue:** 2

Cite as: Dogu, U., Akyuz, F.K., Feyzioglu, A., Ersoy, S., "Computational Fluid Dynamics Simulation of a Two-Phase Flow Model with a Cylindroconical Structure for Optimization of Liquid Flow", Hendese, Vol. 1, Issue 2, Pages 98-101, 2024.

Doi: 10.5281/zenodo.13996532

1. INTRODUCTION

Hydrocyclone pumps are systems that provide the transportation of liquids or gases with mechanical power [1,2]. They move fluids using hydraulic power and provide flow with a rotary motion [3-7]. Hydrocyclone pumps are used in a variety of industrial applications such as water treatment plants, the oil and natural gas industry, mining and chemical processes [8-12].

In recent years, the focus of scientific developments on hydrocyclone pumps has been on more efficient and energy-saving designs [13-17]. These developments aim to provide advantages such as higher performance, lower energy consumption and longer durability.

Scientific studies on hydrocyclone pumps focus on the following (Table 1):

Table 1. Scientific studies on hydrocyclone pumps [18-25].

Scientific Studies	Explanation
Fluid Dynamics Simulations [18,19]	Computer-aided design and fluid dynamics simulations are used to better understand and optimize the internal flow characteristics of hydrocyclone pumps. These simulations are an important tool for evaluating design changes to increase pump efficiency and reduce energy losses.
Innovative Material Use [20,21]	The development of high strength and wear resistant materials is important to increase the durability and longevity of hydrocyclone pumps. New materials can reduce maintenance requirements and extend operating times by improving wear resistance.
Intelligent Control Systems [22,23]:	Intelligent sensors and control systems can continuously monitor and optimize the operating conditions of hydrocyclone pumps. These systems can monitor flow rate, pressure and other important parameters in real time, allowing the pumps to operate more efficiently.
Energy Efficiency Focused Designs [24,25]:	Various technological developments are being made to design more efficient hydrocyclone pumps. These developments focus on developing pumps that can provide higher flow rates with lower energy consumption, provide more efficient fluid transportation and reduce operational costs.

This study aims to use hydrocyclone pumps in a more sustainable and economical way. The results obtained in the study are to make hydrocyclone pumps advantageous in industrial areas where they will be used and to develop a system that will operate in the optimum operating range. Analysis and simulation techniques will be used to provide improvements in Separation and Filtration, High Efficiency, Low Maintenance Needs, Compact Design, Durability and Long Life. In addition, it is desired to reach a minimum outlet pressure of 8.5 bar for the system we want to design. Researcher contribution will be provided in the evaluation of simulation and analysis results and optimization of the system. It is aimed to make prototype production in line with the findings to be obtained and to carry out the study in a controlled environment. The main idea of this study will be to improve the separation and filtration of solids and liquids in hydrocyclone pumps with the product to be developed.

2. MATERIAL AND METHOD

In this work, our purpose is to find pressure loss occurring in our two-way piping systems by using numerical simulation. First of all, fundamentals about pressure loss is given to grasp an idea how the pressure loss is classified and formulated. When we talk about straight piping system, pressure losses occur only due to major losses which is expressed by equation 1.

$$\Delta P = fLD\rho V22g \quad (1)$$

ΔP=Pressure drop [Pa]
f =Darcy friction factor [-]
L=Length of the pipe [m]
D=Diameter of the pipe [m]
V=Averaged flow velocity [m]
g=Gravitational acceleration [m]

But if we have equipment's that changes or effect flow field, these equipment-like valves, filters etc creates extra pressure drop occurs which is called minor losses as expressed by equation 2.

$$\Delta P = KL\rho V22g \quad (2)$$

KL=Minor loss coefficient [-]
These are two contributors of pressure drop in our system.

2.1. System Geometry

In numerical simulation methodology, we need only the geometry that fluid flows within. For this reason, flow domain is extracted within the flow equipment's given in Figure 1.

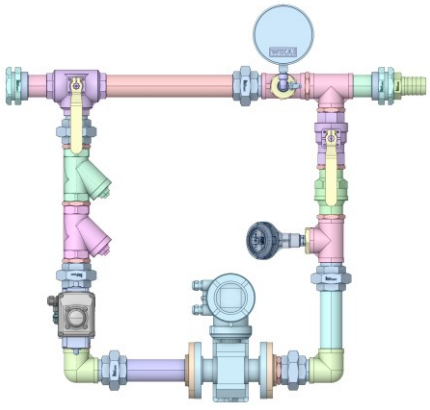

Figure 1. Flow equipment's.

Flow domain is given in Figure 2 and created in SpaceClaim

2021 R1 3D CAD modeling software.

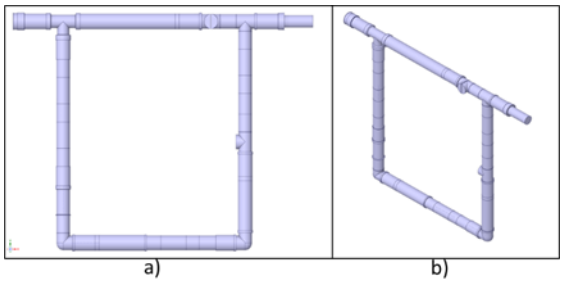

Figure 2. Flow domain a) front view b) isometric view

The piping system, one of the ways (upper way) is closed by a valve. For this reason, flow domain is cut not to allow flow pass through (Figure 3).

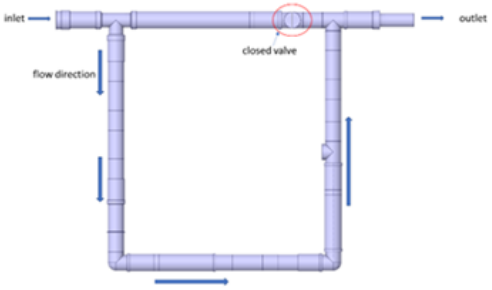

Figure 3. Direction of flow

2.2. Grid Generation

Generations of grid for this geometry were done in mesh modular in Ansys-Fluent version-21- a finite volume method based CFD software (Figure 4). The grid used for the problem is unstructured, having tetrahedral meshing. Quality of mesh is assessed by conducting grid independency test (GIT). To conduct an acceptable CFD simulation, changes in flow variables in the flow domain must be independent of number of grids. GIT as shown in Figure 4, the inlet pressure changes at 73250045 by 1 % percent. For this reason, 73250045 number of grids is chosen for the numerical calculations.

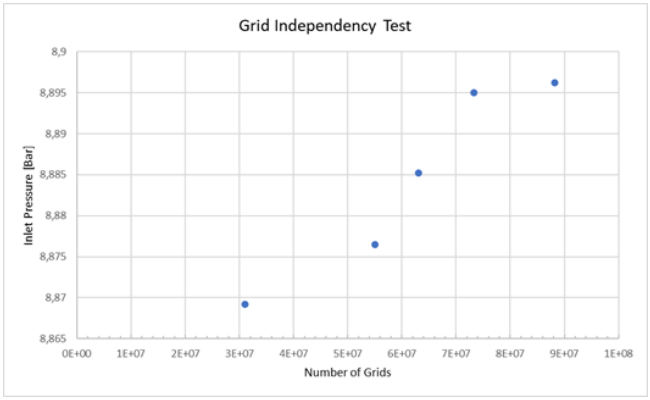

Figure 4. Grid Independency Test

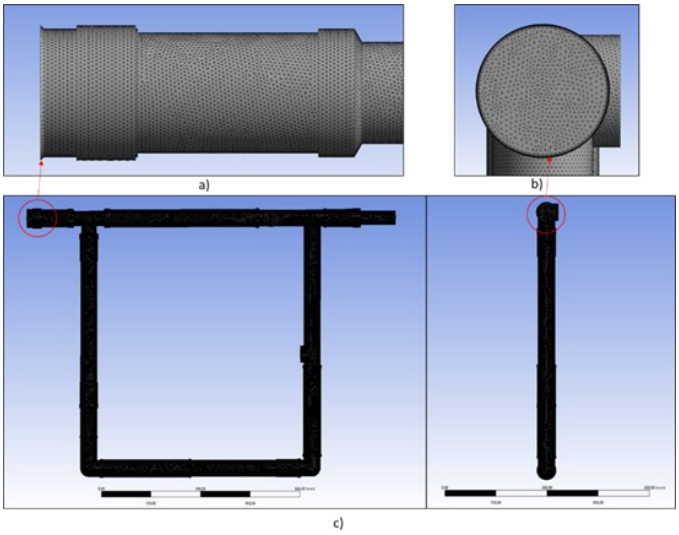

Figure 5. Meshing details, a) Face meshing at the inlet b) Inflation layer near the wall c) Volume mesh of flow domain.

As given in Figure 5, flow domain is meshed by adopting tetrahedral meshing. As can be seen from Figure 5, to resolve flow properties near the wall, inflation layers is created in a way that y+ value is kept below 1.

2.3. Boundary Conditions and Model

Fluid pressure the outlet was taken as 8,4 bar with the turbulent intensity of 1% and hydraulic diameter of 42 mm. At the inlet, fluid(water) volume flow rate was taken to be 360 lt/dk. The wall of the pipeline is taken as hydrodynamically smooth with no slip condition.

Pressure based CFD solver with the SST-k-ω turbulence model is adopted. To get the pressure distribution along the pipe, SIMPLE- pressure velocity coupling was used because it converges faster. Convergence criteria are set at 10-5. A second order upwind scheme is used for pressure, momentum, turbulent kinetic energy and turbulent dissipation rate.

3. RESULTS AND DISCUSSION

CFD allows us to make detailed analysis of flow field. In Figure 6a we can see that pressure gradually decreasing with the direction of the flow which is naturally expected flow behavior and from the T junction near the inlet to the closed valve position where flow stops, the pressure almost the same as expected since there is no flow.

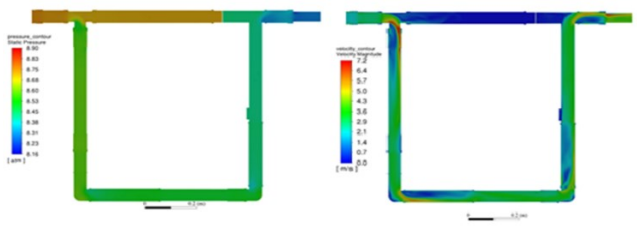

Figure 6. (a) Pressure distribution along the pipe, (b) Velocity distribution along the pipe

In Figure 6b., velocity distribution along the pipe is shown. There are 4 bends with 90° angle, in this areas flow, flow

separation occurs and much of the pressure losses takes place in these areas. Maximum flow velocity was found to be 7,2 m/s while passing T junction near the inlet. Total pressure loss was found to be 8,8954 bar.

4. CONCLUSIONS

In this study, a flow model with a liquid fluid and a cylindrical cone structure with one and two phases was calculated. In addition, the computational flow dynamics of the flow model was simulated. According to the analysis and flow dynamics simulation, the total pressure loss in the pipe system was determined as 8.8954 bar. The maximum speed occurs near the inlet T connection and at approximately 7.2 m/s. In order to reduce the total pressure loss along the pipe, the chances in the cross section of the flow field can be reduced and the bending angle can be increased. As a result, an accurate design and modeling was made for our desired minimum 8.5 bar outlet pressure value

ACKNOWLEDGEMENTS

This work was carried out with FESTO R&D facilities.

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MUŞ ALPARSLAN ÜNİVERSİTESİ
HENDESE TEKNİK BİLİMLER VE MÜHENDİSLİK DERGİSİ
MUŞ ALPARSLAN UNIVERSITY
JOURNAL OF HENDESE TECHNICAL SCIENCES AND ENGINEERING
Muş Alparslan Üniversitesi Külliyesi Teknik Bilimler Meslek Yüksekokulu, 49250, Muş, Türkiye
https://dergipark.org.tr/en/pub/hendese/board
e-ISSN: 3023-7777
HENDESE Ekim 2024, 1 (2): 50-114
Cilt / Volume: 1 **Sayı / Issue: 2** **Yıl / Year: 2024**

Evaluation of Structurally Integrated Surface Articulation (SISA) Panels for Architectural Engineering Applications

Fayza Nur YILDIRIM[1]

[1]*Faculty of Engineering, Ankara University, Ankara, TÜRKİYE*
feyzamimar@gmail.com —ORCİD 0000-0002-9723-5740

Article Information

Article Types	Research Article
Received	20 September 2024
Accepted	24 October 2024

Year: 2024 | **Volume:** 1 | **Issue:** 2 | **Pages:** 102-114

Cite as: Yildirim, F. N, "Evaluation of Structurally Integrated Surface Articulation (SISA) Panels for Architectural Engineering Applications", Hendese, Vol. 1, Issue 2, Pages 102-114, 2024.

Corresponding Author: Feyza Nur YILDIRIM

https://doi.org/10.5281/zenodo.13996542

HENDESE TEKNİK BİLİMLER ve MÜHENDİSLİK DERGİSİ
JOURNAL of HENDESE TECHNICAL SCIENCES and ENGINEERING
RESEARCH ARTICLE

Evaluation of Structurally Integrated Surface Articulation (SISA) Panels for Architectural Engineering Applications

Feyza Nur YILDIRIM[*1]

[*1]*Faculty of Engineering, Ankara University, Ankara, TÜRKİYE*

(**Received:** 20.09.2024, **Accepted:** 24.10.2024, **Published Online:** 27.10.2024)

Keywords
Composite,
Structurally Integrated Surface Articulation (SISA),
Surface panels

ABSTRACT

This research explores the efficiency of a newly developed Structurally Integrated Surface Articulation (SISA) system for a variety of structural engineering applications, such as exterior building facades and solar panels. SISA is a modular system that consists of dynamically adjustable three-dimensional surface panels supported by an internal wire-frame space structure. The articulation techniques vary depending on the specific function of the panels, with configurations designed to optimize structural performance through composite action between the outer surface panels and the internal frame. Materials such as plastic, smart glass, and sheet metal are evaluated in conjunction with polyhedral and honeycomb configurations, including tetrahedral and convex polygonal forms. The research emphasizes enhancing large-scale structural efficiency by integrating modern frame systems with surface articulation. It also explores the evolution of architectural design and presents case studies using SISA-based structures to highlight the potential improvements in structural integrity. By addressing both material properties and design techniques, the study aims to demonstrate how the SISA system can provide significant advancements in architectural engineering.

Corresponding Author: feyzamimar@gmail.com
Volume: 1 **Issue:** 2

Cite as: Yildirim, F.N, "Evaluation of Structurally Integrated Surface Articulation (SISA) Panels for Architectural Engineering Applications", Hendese, Vol. 1, Issue 2, Pages 102-114, 2024.

Doi: 10.5281/zenodo.13996542

1. INTRODUCTION

The roles and functions of architecture have evolved with the global rise of architects and engineers, leading to the development of new "Generic Building Types." Architectural concepts traditionally address three key challenges: providing protection, ensuring durability through materials and gravity, and creating aesthetic beauty [1]. Design involves three main elements: horizontal and vertical subdivisions and the balanced grouping of masses [2]. In modern architecture, particularly under the High-Tech trend, traditional configurations are being replaced. Imagining and recording spatial configurations have become key activities that differentiate architects and engineers from other building planners [3]. Modern constraints demand innovative structural solutions, making composite materials and optimized configurations increasingly relevant. Understanding historical architectural developments can provide valuable insights for contemporary design challenges.

More rigid methods are needed to address the design problems of today, therefore improving composite structures is essential to finding complete and efficient solutions. Architectural practices have changed throughout time and comprehending them now requires looking at pertinent historical instances and arrangements. Severe weather, earthquakes, and other environmental pressures pose a constant hazard to buildings, which frequently necessitates ongoing damage and repair. The ground-breaking "Generic Building Type" offers novel ideas for the fabrication, assembly, and installation of building components while being resilient enough to withstand natural disasters. This approach may increase both short-term cost-effectiveness and long-term economic gains by utilizing local labour resources. Technological developments offer a variety of intriguing ideas for contemporary architectural and technical building kinds. The true challenge is embracing these innovative, forward-thinking ideas and eschewing the outdated, inflexible industrial methods.

Not only are planning and designing essential to surroundings today, but they also place a strong emphasis on modernism, artistry, and aesthetics. In order to sustain and retain ground loads, the new generic building type takes into account both geometric strength and deformation ability. Lightweight structural frameworks by interstitial composite panels are one way to accomplish this purpose. Because these systems are prefabricated, considerable energy savings are possible, and the buildings can endure environmental stressors like tornadoes. The system includes an earth cover supported by a low-profile, double-envelope, clear-span space frame. The term "structural articulation" describes how the fragmentation of form and face divides huge, heavy sections or concentrated blocks into human-sized components.

This article presents examples supported by a literature review and offers a case study of a project designed by SISA. Within the framework of structural analysis and engineering principles, the study examines the performance of large-span structural systems, evaluating innovative solutions of SISA in the context of project design. The work addresses applications aimed at improving structural efficiency from both theoretical and practical perspectives, with a focus on architectural engineering approaches.

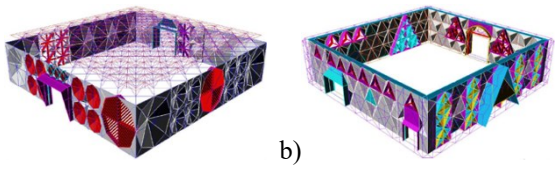
2. A NEW GENERIC METAL BUILDING TYPE: STRUCTURALLY INTEGRATED SURFACE ARTICULATION (SISA)

Using standard components, SISA is designed to be a "Generic Building System and Technology," enabling the implementation of many configurations, permutations, and combinations of structural engineering applications to encompass a wide range of specific and multipurpose functions. SISA is a modular system comprising three spaces and articulated, geometrically distorted sheet metal and sheet plastic surface panels. Unlike traditional two-dimensional surface systems that are added to an existing steel superstructure, this system combines surface and structural integration from the start, removing the need for separate massive structures and applied dead loads. Moreover, stiff structural foam may be laminated or otherwise connected to these surface panels to improve the structural qualities of the panel configuration through composite action.

Using the exponential structural benefit of surface deformation and geometric configuration, SISA integrates "Façade and Structure" into a single, harmonious module. SISA is an exceptionally strong weight system, each of whose parts can be set up to work in concert with one another to enable single-unit characteristics in response to be dividing static and dynamic stresses. SISA adds dead-load stress to a pre-erected structural system; it is not an independent cladding system.

The SISA system introduces innovative concepts for high-rise buildings, utilizing "fractal" and "honeycomb" patterns within an ultra-light space frame. This approach allows for the construction of very tall buildings with minimal heavy steel or concrete, potentially using only modified front-end loaders for assembly. This cutting-edge, high-tech approach offers significant economic benefits and advancements in urban development. SISA can be applied from the exterior in deep, linear, inter-panel pockets, formed along each panel edge.

Fig. 1 show the SISA configurations inspired by algorithms and geometric constraints. The design focus on the maximal surface with multi-dimensional symmetries to create continuous honeycomb surfaces which are highly expandable.



a) b)

Figure 1. a) The SISA design uses triangular disphenoid form b) The form design octagonal disphenoid honeycomb.

3. EXPLORING THEORETICAL FRAMEWORKS OF SISA IN CONTEMPORARY BUILDING DESIGN

The method of articulation influences the design of joints in architectural projects, affecting how shapes, dimensions, scales,

ratios, and visual weight are perceived. The contrast between the colour of the surface and its surroundings impacts the tonal value and visual effects of the design. In modern structural architecture, articulation refers to the design of joints between formal elements using patterns, colours, textures, tones, forms, shapes, and lines within structural design. Each section of a work is connected through these joints, ensuring that individual pieces fit cohesively into the overall composition [4]. Modern architectural perspectives on articulation focus on creating iconic structures. This concept applies to structural and engineering elements, as well as enclosure elements like wall systems and construction techniques [5].

Articulation can be defined through some key steps: differentiating adjacent surfaces by varying materials, colours, designs, and aesthetics. Each part features unique linear elements that are separated by adjacent planes, and removing corners can define boundary planes. The way light interacts with the form helps in creating distinctive shapes and emphasizes sharp contrasts in tonal values along edges and corners [4]. Integrating these elements externally enhances the exterior aesthetics of the building while keeping the interiors open and versatile for design and functionality. The goal of SISA is to create an environmentally friendly, low-impact, semi-autonomous ecosystem with high-tech attributes that complement form, function, and long-term economic viability, representing a new architectural paradigm for megacities.

In the provided examples of related configurations, multiple lattice systems are layered. A given topology can be supported additively from within the shell or through a combination of both methods, depending on specific load requirements. Beyond basic shapes like cubes, cylinders, and cones, the use of generic space-frame systems can be extended to create shell structures with limited or complex surface geometries. Lattice and diaphragm combinations can be designed into large, transportable multi-panel modules for sequential field assembly. Additionally, flexible truss lattice systems are ideal for quick assembly and welding, making them suitable for large spaces like botanical conservatories, particularly in double-envelope designs that provide plenum without the need for ductwork. The structural benefits of surface deformation are evident in many everyday objects, such as steel or plastic panels and modular corrugated siding. Modern, high-tech prototypes are not only acceptable but often preferred. In rural areas of China, India, Pakistan, Mexico, South America, Africa, and parts of rural America, conventional metal building types are prevalent [6].

SISA aims to develop modular components for:

- Innovative metal building designs featuring three-dimensional structural systems.
- High-strength canopies suitable for various applications such as festival halls, market structures, covered walkways, and pedestrian bridges.
- Space applications, including solar collectors and reflectors for energy transmission to Earth.
- Conservatory structures, using sheet metal instead of glass as a diaphragm for purposes such as field hospitals, modular housing, aviaries, butterfly houses, gazebos, pavilions, and outdoor furniture.

3.1. Theoretical Building Science with SISA

3.1.1 House systems

SISA system offers innovative solutions for modern housing systems through modular sheet components. This approach integrates three-dimensional structural frameworks, enhancing both functionality and aesthetics. This research has highlighted the potential of SISA in creating durable and versatile residential environments, benefiting from its efficient use of materials and ability to withstand environmental stresses.

One significant advantage of SISA in residential applications is its adaptability to different building types and climates. For instance, its use in modular housing allows for rapid assembly and customization, which can be particularly beneficial in areas with limited construction resources or in emergency situations [7]. Additionally, the components of SISA offer robust solutions for creating energy-efficient and environmentally friendly homes [8].

Figure 2 below illustrates the Desert Wing House, designed on a three-acre plot, where the structure features a combination of rammed earth formed into brick-like shapes or layered rows [9]. The design focuses on integrating walls and large glass surfaces to capture scenic desert views. The articulation is evident through the interplay of glass, walls, and roof, all forming a unified small building concept.

Figure 2. Desert Wing [10].

3.1.2. Structural systems for expansive span frames

Designing expansive span frames necessitates advanced structural systems capable of addressing the complexities of large-scale projects. The approach of SISA leverages modular and lightweight strategies to integrate cutting-edge materials and construction techniques, resulting in strong, adaptable, and economically efficient structures. The significance of modular construction in contemporary architectural practices, particularly for extensive span systems [11]. By employing space frame systems, SISA optimises load distribution and reduces reliance on heavy materials, thereby strengthening structural performance. Additionally, this method promotes sustainability through the use of prefabricated components, which helps decrease environmental impact and shorten construction periods.

Structures subjected to compression loads generally exhibit reduced efficiency compared to those under tension loads. While tension structures typically fail through material yielding, compression structures are prone to buckling before material failure occurs [12]. The system can include tessellated, arched, and folded-plate configurations, employing single curvature combined with geometric strength or compound curvature with enhanced geometric support.

Figure 3 illustrates the Heydar Aliyev Cultural Centre, which was designed to become a central symbol of the cultural identity of the nature. The design of it fosters a seamless, fluid connection between its surrounding plaza and the interior of the building [13]. This project serves as a prominent example of expansive span architecture, integrating a fluid frame system that interacts dynamically with various interior levels.

Figure 3. Heyder Aliyev Cultural Centre, Azerbaijan [14].

3.1.3. Structural systems for expansive span frames

Adaptive use voids are being integrated into all spaces, with SISA systems employed as cladding. Honeycomb structures, which are frequently found in nature, offer notable strength, rigidity, and lightness. These properties make them suitable for diverse applications, including satellite components.

Advanced structural systems are essential for the design of high-rise buildings, particularly when incorporating innovative strategies such as those developed by SISA. The approach of SISA utilizes modular and lightweight components to improve the performance and efficiency of tall structures. Modular construction is crucial for addressing the complexities of high-rise projects, offering both adaptability and strength [8,15]. The systems of SISA employ space frames and advanced materials to provide effective load distribution, reducing reliance on traditional, heavy construction materials. This methodology not only enhances structural integrity but also promotes sustainability by minimizing environmental impact and shortening construction time through the use of prefabricated and plant-based materials [16]. Modern high-rise designs benefit from structural systems that integrate geometric principles with material properties to optimize performance under various loads [17]. Adopting concepts of the SISA represents a significant advancement in high-rise construction, fulfilling contemporary demands for efficiency and environmental sustainability.

Figure 4 illustrates the Origami Building, which features a prominent glass façade complemented by a secondary layer of screen-printed marble patterns. This design creates an origami-like effect, visible both from inside and outside the building [18]. The façade employs layered curtain panels arranged in a fractal honeycomb pattern, enhancing the exterior of the building. The sophisticated building system manages shading through a complex façade algorithm, optimizing light control and aesthetic impact.

Figure 4. Origami Office Building [19].

3.2. Relationship Between Structure and SISA

The relationship between structural systems and architectural design has seen significant evolution, especially with innovative approaches such as those employed by SISA. This relationship emphasizes the crucial interplay between structural efficiency and aesthetic design, demonstrating how modern architectural advancements can seamlessly integrate with robust engineering principles [20].

Surface Articulation and Structural Integration

Surface articulation involves the careful design and placement of a surface elements of the building to enhance both its visual appeal and functional performance. In terms of structural systems, this entails using materials and geometric configurations strategically to achieve desired visual and structural effects [20-21].

The Approach of SISA to Structural and Architectural Integration

The methods of SISA illustrate this integration by using modular and lightweight structural elements that complement advanced architectural designs. For instance, the Hearst Tower of Norman Foster utilizes a triangulated diagrid structure that reduces steel frame usage by 20% compared to conventional designs (Fig. 5). This not only boosts structural efficiency but also enhances the unique aesthetic of the building, contributing to its overall identity. The design of the building, inspired by origami, exemplifies how surface articulation can be used to create complex, visually engaging forms while maintaining structural stability [20,22].

Figure 5. Hearts Tower [23].

Implications for Modern High-Tech Architecture

The approach of SISA, combined with contemporary high-tech architecture, shows how structural systems and architectural design can work together to meet both functional and aesthetic requirements. By utilizing modular construction, space frames, and cutting-edge materials, SISA addresses current needs for efficiency, sustainability, and visual impact [20,24]. This collaboration underscores the importance of ongoing interaction between engineers and architects to advance building design.

In conclusion, the interaction between structural systems and surface articulation, as demonstrated by SISA and modern high-tech projects, reflects the changing landscape of architectural design. This integration not only progresses the field of architecture but also contributes to the creation of more efficient, sustainable, and visually impressive buildings [25].

4. METHODOLGY

The SISA methodology, particularly in modular architecture, integrates advanced surface articulation techniques that emphasise both functionality and aesthetic value. Fig. 6 demonstrates how the various components of the proposed SISA align with and contribute to achievement of the research objectives. Modular building design aims to create a balance between urban picturesque and high-modern architectural themes. Industrial materials such as steel and smart glass are often used to enhance the strength and durability of modular structures improve both the visual impact and structural efficiency of these buildings [26].

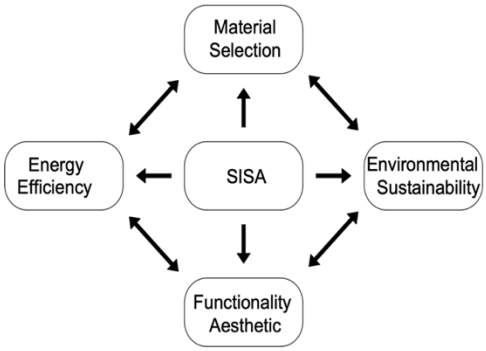


Figure 6. The research methodology adopted for the study of the SISA structures.

In SISA, the selection of materials is paramount to ensuring structural resilience, environmental sustainability, and resource efficiency. Practitioners of modular architecture focus on materials that reduce the environmental footprint while maintaining long-term availability, such as recyclable glass or low-impact materials [26-28]. While sheet metal and aluminium are common for surface grids, the design flexibility of modular systems allows for the integration of alternative materials, depending on project-specific requirements and cost-efficiency considerations [29].

The use of surface articulation techniques, such as tessellated or folded-plate geometries, further enhances both structural integrity and energy efficiency. These configurations optimise load distribution, maximising strength while reducing material use. In addition, they contribute to thermal efficiency, as the façade interacts with environmental conditions to regulate internal temperature, minimising the need for artificial heating and cooling systems.

Semi-autonomous energy management is also a core feature of the SISA methodology, achieved through innovative double-envelope systems. These systems, constructed using glass and plastic, reduce overheating by facilitating passive ventilation during cooling cycles and trapping heat during heating cycles. Airflow is strategically routed through sub-floor and ceiling plenums, enabling radiant heating and cooling. This energy-efficient approach is often supplemented by renewable technologies like solar, wind, and geothermal systems, aligning with the emphasis of SISA on sustainability.

In conclusion, the integration of SISA of surface articulation and modular design leads to high-performance, energy-efficient structures that are not only visually striking but also functionally resilient. The methodology exemplifies the balance between structural innovation and environmental responsibility, setting a precedent for modern sustainable architecture.

4.1. Frame Geometry

Whether functioning as edges and interstitial spaces acting as diaphragms in folded plate systems or as struts with empty interstitial spaces in space-frame systems, these elements offer a method to investigate and analyse plate and frame structures. Structural components utilizing folded plate and space frame systems for universal structural applications derive from developable or para-developable surface configurations. These configurations allow for the breakdown of surfaces into parts suitable for fabrication and assembly. Specific methods of joining components in structural and volumetric arrays permit precise alignment in positive or negative fold positions, and enable the determination of rectilinear, curvilinear, and skewed surfaces, along with the enclosure of amorphous volumes.

The interest in space frame structures has been invigorated by new structural forms. Space frames exhibit significant structural capacity and visual appeal and are used for both long-span and mid- to short-span enclosures. The geometry of the space frame offers several advantages, including suitability for various surfaces, high static strength, lightweight construction, lower production costs, mass production in factories, and flexibility in the positioning of numerous members in space. Space frames can be formed with either planar or curved surfaces.

The mechanism of SISA involves four distinct combinations of layers:

- **Primary:** Space-frame grid structures
- **Secondary:** Internal and external grids; dual and complementary
- **Interstitial:** Internal and external lattices
- **Unit Structural Closure:** A complete space frame determines a honeycomb of tetrahedral components.

The most crucial aspect is that tetrahedral closure and unit stability are determined upon the completion of the wireframe and space frame structure, independent of additional interstitial surface panels or shell components. However, the inclusion of shell surface components in their composite configuration significantly enhances the strength characteristics of the unit system.

4.1.1. Space frame structures

Space-frame structures employ a three-dimensional grid of interconnected elements to create a lightweight and robust framework, as shown in Fig. 7. This design efficiently distributes loads, enhancing the overall strength and stability of the structure while minimising material use [30]. The spatial grid design optimises material efficiency and cost by effectively distributing forces across the framework. This adaptability allows spaceframes to accommodate a wide range of architectural forms, from simple to complex, making them ideal for large-span roofs and intricate façades. Additionally, the open grid structure imparts a contemporary and visually striking aesthetic, enhancing the overall appearance of the building [31]. Spaceframes are particularly suited for expansive structures like sports facilities and exhibition centres and integrate well with elements such as glass façades, combining functionality with visual appeal. Precision in fabrication and assembly is crucial to maintain structural integrity, with technological advancements improving the efficiency and practicality of constructing these frameworks [32].

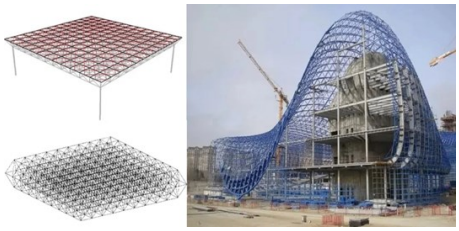


Figure 7. The space-frame Structure in Heydar Aliyev Centre [30].

4.1.2. Space grid structures

The geometry of space grids plays a crucial role in structural engineering by distributing mechanical loads effectively across a network of interconnected elements. Space grid structures can support substantial mechanical loads due to their dense, multi-layered configurations [33], as shown in Fig. 8. These designs incorporate various geometric forms, such as triangular, orthogonal, and tetrahedral shapes, alongside different fabrication techniques. The versatility in materials and geometry allows for numerous variations in joint configurations, optimizing strength, length, and transportability [29].

The dimensions of space grids are influenced by multiple factors, including span height, face shape, building planes, and joint costs. The repetitive nature of space grid elements simplifies fabrication and assembly, enhancing efficiency and reducing complexity [33]. For instance, triangulated grids create continuous, straight edges, while pentahedron units offer substantial coverage and stability. The continuous inward and outward joints around each combined tetrahedron further contribute to the structural integrity and flexibility of the grid system.

These space grids can be visualized through examples such as those involving tetrahedrons and pentahedrons, which are designed to form a network of interconnected units. This design approach simplifies the creation of large, continuous structures while maintaining structural efficiency and aesthetic appeal [29,34].

Figure 8. The space-grade structure in Eden Project, Cornwall UK.

4.1.3. Lattice grid structures

Lattice grid structures are highly regarded in structural engineering for their efficiency and adaptability. These systems employ a three-dimensional network of interconnected members that form a grid-like framework. The lattice grid excels at distributing mechanical loads across the structure, thereby optimizing material usage and reducing overall construction costs. The design of lattice grids supports various geometric configurations, including triangular, orthogonal, and tetrahedral forms [29,31,35]. This versatility accommodates different fabrication techniques and material options, such as aluminium, steel, and plastics.

The lattice grid design facilitates straightforward manufacturing by using repetitive elements, which streamlines both the production and assembly processes. The adaptability of lattice grids allows for modifications in span heights and face geometries, making them suitable for diverse architectural applications, including large-span roofs and intricate facades. The design of the system also allows for a range of joint configurations, which enhances structural strength and durability [36]. This approach to surface articulation effectively balances structural integrity with aesthetic considerations, ensuring both functional and visual effectiveness in complex architectural designs.

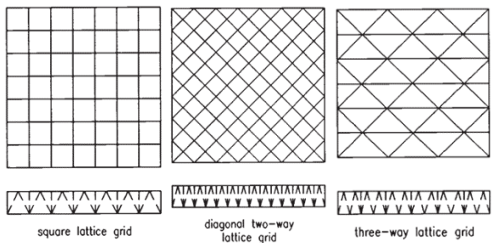


Figure 9. The examples of lattice grid space structures [37].

4.2. Materials of SISA

4.2.1. Sheet Metal

Sheet metal is widely used in structural and architectural engineering due to its adaptability, strength, and cost-effectiveness. It is formed by rolling the metal into thin, flat pieces, easily manipulated through bending, cutting, and forming. These characteristics make sheet metal an ideal choice for both functional and aesthetic applications in construction. The ability to fabricate sheet metal into complex shapes using stamping, deep drawing, and hydroforming techniques has extended its use beyond simple structural elements to more intricate architectural forms. In addition to its formability, the strength-to-weight ratio of sheet metal makes it essential in applications requiring lightweight yet durable materials. Table 1 and Fig. 10 shows the details of sheet metal forming process [38].

Table 1. Sheet Metal Forming Work Step [39].

Properties
A metal sheet is cut from a stock material to produce individual blanks.
The blanks are placed between two tools in a forming machine.
Significant forces from the machine act on the metal sheet.
The upper die (punch) applies pressure, shaping the metal around the lower die.

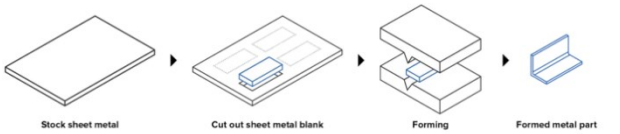


Figure 10. Process workflow for sheet metal forming [39].

Its composition includes a variety of metals, such as aluminium for corrosion resistance, steel for high strength, and stainless steel for enhanced durability and resistance to oxidation. This versatility allows sheet metal to be used in building facades, roofing, and cladding, where both aesthetic quality and long-term performance are critical. In the field of surface articulation, the thinness of sheet metal allows for precise manipulation of the surface, creating complex patterns or articulations that enhance both structural and aesthetic performance [38,40].

The sheet metal is integral in achieving optimal load-bearing properties when used in conjunction with other materials, such as in composite systems where it contributes to the overall stiffness and strength. For example, in honeycomb or lattice configurations, sheet metal adds to the rigidity of the structure while maintaining a lightweight profile, making it suitable for large-span architectural applications. Moreover, its capacity to be recycled and repurposed aligns with modern sustainability goals in engineering, further cementing its role in the future of construction materials [38,40,41].

4.2.2. Glass

Glass is extensively utilized in construction due to its array of benefits, including transparency, chemical resistance, environmental sustainability, durability, accessibility, minimal maintenance, recyclability, and cost-efficiency [42]. In the realm of construction, glass serves various functions, from enhancing aesthetic appeal to improving energy performance. Its properties make it a fundamental material in modern architecture, where buildings without glass facades or windows are virtually inconceivable [43]. Figure 11 illustrates several typical uses of glass in building structures.

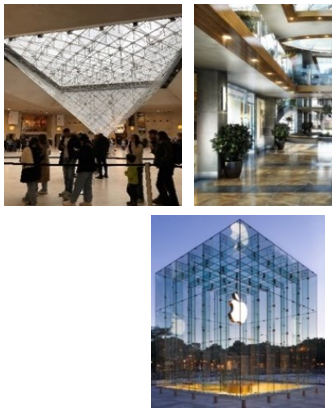


Figure 11. Examples of modern buildings that are using glass for aesthetics, lighting, and more space, etc. [42].

The float glass process, developed by Pilkington in 1959, is used to produce high-quality flat glass efficiently, eliminating the need for extensive finishing processes [44]. This method dominates the glass market, accounting for over 80-85% of glass used in construction. Float glass is commonly used in the building industry for structural window glazing, contributing to well-lit and spacious buildings.

Annealed glass is primarily produced using the float process. In this method, raw materials are mixed and melted in a furnace at approximately 1500°C, creating a molten tin bath. The molten glass is continuously poured onto the tin bath at around 1000°C and gradually cooled to 600°C. During this cooling phase, the glass is drawn over rollers before entering a lengthy annealing furnace (Fig. 12). Tin remains stable in a liquid state at 600°C, allowing glass to float on it. Controlled cooling, or annealing, at the end of the tin bath, ensures a gradual reduction in temperature, which helps to prevent residual stresses. Glass thickness, ranging from 2 to 22 mm, is managed by adjusting the roller speed through the annealing lehr. The glass is then cut into large sheets measuring 3 m × 6 m before being stored. Adjustments in roller speed impact glass thickness and vice versa [42-45].

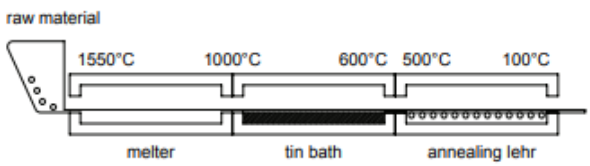


Figure 12. Float glass production process [44].

4.2.3. Plastic

The growing use of plastic materials in construction and engineering projects plays a significant role in the pursuit of efficiency and creativity in modern architecture [46]. This approach aligns with the core principles of SISA, which embraces a design philosophy that balances functionality, aesthetics, and technology in structures. Plastic stands out as a versatile and flexible material employed by engineers and architects to achieve this balance.

With its lightweight nature, design flexibility, and recyclability, plastic complements SISA principles of sustainable and innovative building solutions. For example, plastic materials like PVC and polyethene are used in modern buildings for windows and flooring, providing both durability and energy efficiency [46-48]. According to SISA principles of innovation and high-tech integrated design, plastic materials offer architects and engineers unlimited design possibilities while supporting modern building designs without compromising structural performance.

Plastic meets SISA functional and aesthetic expectations, while also contributing to cost reduction and long-term performance in engineering processes. Additionally, the reusability and recyclability of plastic materials reinforce SISA commitment to environmental sustainability. Structures built using plastic materials offer energy-saving and eco-friendly structural solutions. Plastic, which aligns with SISA innovative design philosophy, merges functionality and aesthetics in both architectural and engineering processes [49]. Fig. 13 below shows a housing complex in Poland designed by Moomoo Architects. The building features Thermopian, an insulating plastic typically used for roofing, applied entirely to the facade. Completed in 2008 in Lodz, the 200 m² structure combines traditional Polish house proportions with a modern, minimalist approach [50].

Figure 13. L House Poland [50].

4.2.4. Aluminium

Aluminium, a nonferrous metal, is extensively utilized in both its pure form and as an alloy across various industrial sectors due to its ease of fabrication and low maintenance needs. Its malleability allows for effortless pressing and shaping, making it suitable for a wide range of applications. The resistance of the aluminium to corrosion and superior thermal properties enhances its effectiveness in exterior applications. Key attributes include a high strength-to-weight ratio and excellent conductivity, which contribute to its use in residential buildings, automobiles, aircraft, and electronic devices [51-53].

In the context of SISA, aluminium aligns well with the principles of combining functionality, aesthetics, and advanced technology. SISA focuses on integrating innovative materials to improve structural performance and design efficiency. The high ultimate tensile strength and versatility of aluminium, especially in extrusions and flat-rolled sheet plates, support the creation of durable and efficient structures. Using aluminium in SISA-based designs enables engineers and architects to achieve both structural integrity and aesthetic flexibility, adhering to contemporary architectural and engineering standards and the versatility of aluminium, allowing for effective incorporation into structural designs. This process helps achieve reduced loads and extends the service life of structural components, making aluminium a valuable material in modern engineering and construction.

5. CHARACTERISATION AND ANALYSIS OF SISA FACE TYPES IN STRUCTURAL APPLICATIONS

In the design of SISA facades, there is an extensive range of configuration possibilities. The theory behind this is provided by examples of various façade edge cells, including disphenoid, disphenoid tetrahedral honeycomb, convex uniform honeycomb, and the frequently used tetrahedron. Designing an innovative façade involves a creative process that integrates perspective vision and the consideration of different image layers within the building.

5.1. Frame Geometry

Incorporating provided materials into these designs offers significant benefits due to its versatility and adaptability. The extrusion process enhances the ability of the aluminium to be shaped into diverse forms, which aligns well with the innovative configurations discussed. The properties of aluminium support the creation of complex façade designs while maintaining structural integrity and aesthetic appeal. Its application in SISA facades allows for the realisation of intricate and visually striking building envelopes that meet both functional and design objectives.

5.1.1. Disphenoid

The disphenoid is defined as a wedge-shaped crystal form in the tetragonal or orthorhombic system, characterised by four triangular faces that alternate with the faces of a tetragonal or orthorhombic dipyramid. This shape is symmetrical about three mutually perpendicular diad axes in all classes except the tetragonal-disphenoid, where an inverse tetrad axis of symmetry generates the form [54]. In a disphenoid, all edges are of equal length, and any third component measurement exceeds the square of the first and second components squared [55]. The vertex angle of any disphenoid is equal to two right angles, though the edges may vary in separation. To construct a disphenoid, one must cut out the shape from a triangular plane and fold it through the midpoints of its lengths [56].

Figure 14 illustrates disphenoid configurations created by combining three tetrahedra that share faces. In this structure, the edges of the disphenoid form pairs of symmetrical configurations where two adjacent cells interconnect. Each vertex of the disphenoid is identical, and the sum of the face angles at each vertex totals two right angles. Additionally, all

faces of the disphenoid are congruent, with triangles arranged in a specific pattern. By integrating disphenoid patterns into SISA designs, aesthetically pleasing structures can be achieved complex that leverage the geometric precision and strength inherent in these configurations.

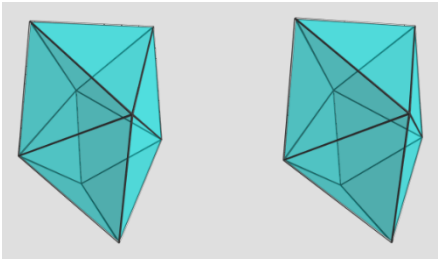


Figure 14. The disphenoid configuration that combines a tetragonal and orthorhombic dipyramid [57].

5.1.2. Tetrahedral disphenoid honeycomb

This configuration represents a space-filling tessellation comprised of identical tetragonal disphenoid cells, each defined by four isosceles triangle faces. The arrangement of these cells forms a lattice that mimics the structure of a body-centred cubic lattice, enabling both efficient space usage and enhanced structural stability. The tetrahedral disphenoid honeycomb, specifically, is characterized by its surface covered with a honeycomb pattern, where each cell has a transitional plane with four identical triangular faces [58]. The cells in this configuration can be subdivided through their central edges, resulting in a pattern where two faces and two sides align vertically.

Figure 17 illustrates the uniform tessellation in three-dimensional space, where the cells consist of pairs of identical isosceles triangular faces. Each edge of the tetrahedral disphenoid is enclosed by this tessellation. A cell is situated with central points that connect pairs of triangular faces, extending through the centre points of the corners, edge vertices, and face centres.

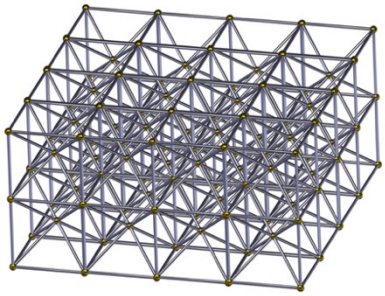


Figure 15. The tetrahedral disphenoid honeycomb configuration [58].

5.1.3. Tetrahedron

A tetrahedron is a polyhedron consisting of four triangular faces, each meeting at a common vertex. This geometric shape can be folded from a single piece of flat material, such as paper, creating a sturdy structure [59]. On a conventional plane, the architectural faces of a tetrahedron are not typically prioritised for placement. However, tetrahedral diagrams provide insight into the folding parameters, which are integral to its form. Tetrahedron, known for their elegance and flexibility, are often applied in layers to achieve aesthetically pleasing designs [60].

Figure 16 below presents a pavilion in Montreal, Canada, where the roof is composed of tetrahedral pyramids of varying sizes. The design utilises a tetragonal framework, serving as a prototype for new construction methods. By relying on a single folded system, the structure avoids the need for additional complex components.

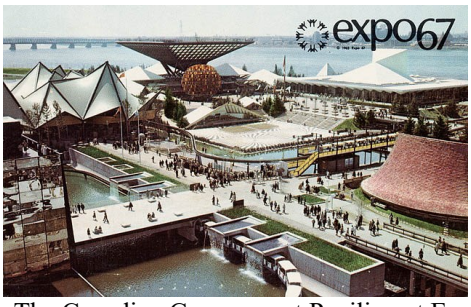


Figure 16. The Canadian Government Pavilion at Expo '67 in Montreal [61].

5.1.3. Octahedron

An octahedron is a polyhedral shape characterized by eight triangular faces, twelve edges, and six vertices [62]. This geometric structure has been applied in architectural design due to its mathematical symmetry and capacity to form stable frameworks. Octahedral configurations are frequently employed in lightweight construction materials, such as honeycomb structures, owing to their ability to distribute loads efficiently. These shapes often serve as integral elements in spaceframe systems, where they provide structural rigidity while maintaining a low weight-to-strength ratio [29]. Octahedral lattice system is frequently used in spaceframe designs, as illustrated in Figure 20. These systems allow for the assembly of strong, self-supporting frameworks, which can be easily transformed, dismantled, and rebuilt.

Figure 17. The Octahedron pavilion by LMNTechStudio [63].

5.2. The Advantages of Geometric Shapes in SISA

The geometric shapes presented above offer significant potential for enhancing structural integration and performance. Each of these shapes presents various advantages in SISA:

- **Disphenoid:** In the context of SISA, the disphenoid shape enhances both lightness and durability within structural frameworks. Its capacity to provide superior stability under diverse loads is particularly beneficial for integrating components into complex systems, ensuring efficient and resilient structural performance.

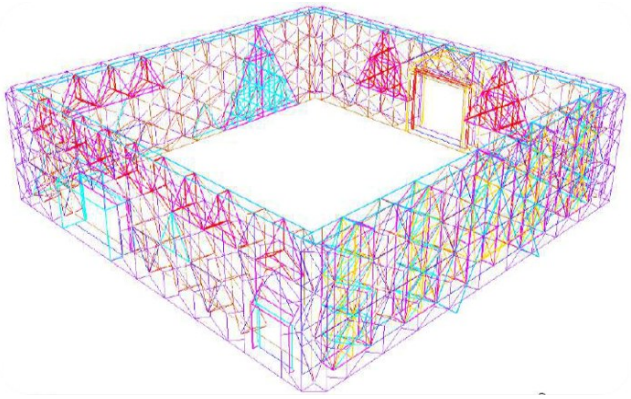
- **Tetrahedral Disphenoid Honeycomb:** The tetrahedral disphenoid honeycomb structure is highly advantageous for SISA applications, offering an excellent weight-to-strength ratio and substantial rigidity. Its lightweight yet robust nature makes it ideal for incorporating into advanced structural systems, while its optimal use of internal voids contributes to enhanced performance and structural integrity.

- **Tetrahedron:** Within SISA frameworks, the tetrahedron is recognised for significantly improving structural strength and stability. Its ability to provide effective support under varied loading conditions makes it a versatile component in architectural designs, facilitating flexible and robust structural solutions.

- **Octahedron:** The symmetrical and balanced structure of the octahedron is highly beneficial in SISA, addressing various engineering challenges with its inherent durability and aesthetic appeal. This geometric shape enhances the overall efficiency and visual impact of integrated structural systems, offering both functional and design advantages.

6. A COMPLEX STRUCTURE ENGINEERED USING SISA

The figures presented illustrate a conceptual design developed through SISA. The design incorporates disphenoid, tetrahedral disphenoid honeycomb, and convex uniform honeycomb configurations. The roof structure employs a tetrahedral disphenoid honeycomb arrangement, while the walls feature two distinct geometric forms to demonstrate the versatility of SISA in applying uniform forms throughout the design. The rounded corners of the structure enhance the continuity of surfaces, facilitating a seamless transition into a horizontal polygonal configuration. The interplay between the façade elements and the roof and wall structures effectively demonstrates the purpose of the articulated frame geometrical panels, both structurally and architecturally. The integration of edge styling and the arrangement of open and closed panels within a rigid system create a cohesive and functional combination.



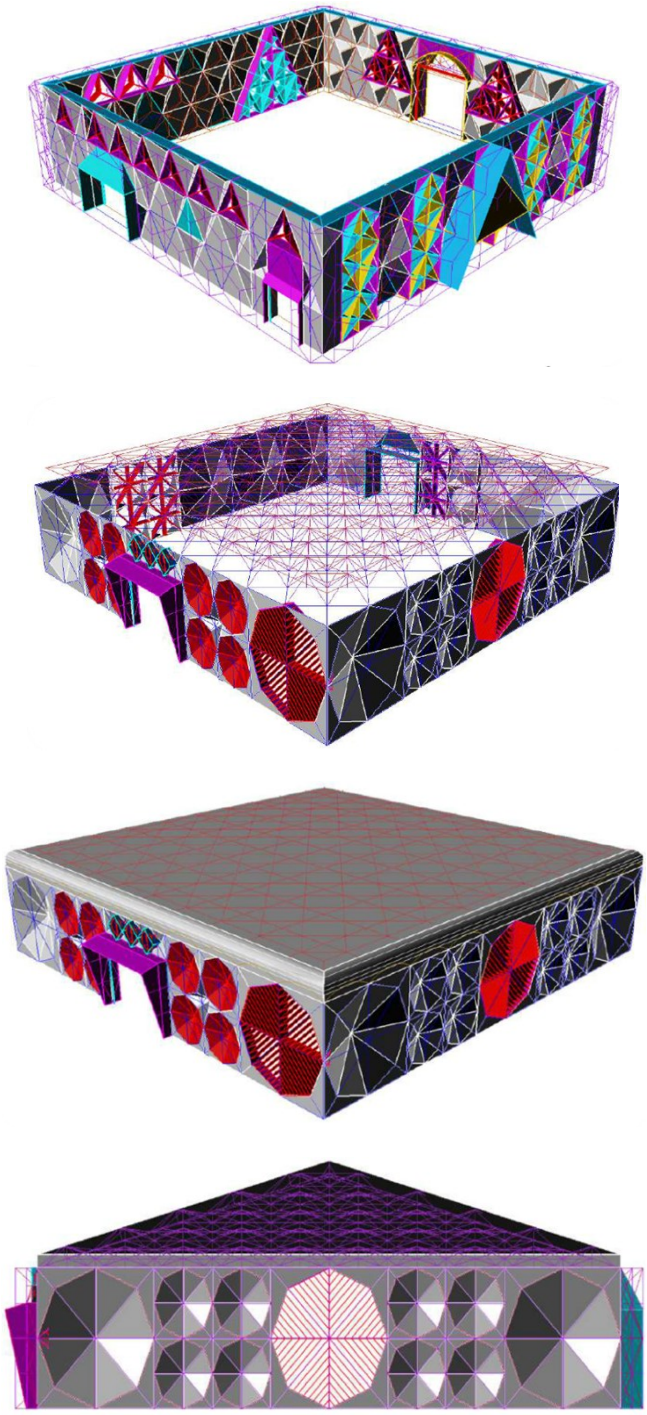


Figure 18. Conceptual design of a SISA-optimised structure using geometric configurations with sectional views.

6.1. Results and Discussion of the Presented SISA Design

The objective of this design was to investigate how SISA facilitates modifications in spatial design through effective surface articulation. SISA is proposed as a versatile system, allowing various combinations and permutations for conventional metal building facades. Without the inclusion of steel, smart glass, and plastics, implementing SISA would be unfeasible. The integration of space frame and folded plate systems in this design demonstrates a harmonious construction approach. Space frame components are intentionally buckled

and shaped to form independent edges. This innovative approach signifies a shift in high-rise architecture, positioning SISA as a valuable building system with multifaceted functions in modern manufacturing.

The design is articulated through its exterior faces and frames, with edges providing a connection between new architectural configurations and composite designs. The SISA network is structured as a gradient system of layered sections, ensuring efficient structural performance and cost-effective construction. It connects both exterior and interior systems, featuring form lanes with a distinct identity for structural foam. The design addresses seasonal protection and shapes connections with regulated transitions. Key advantages include the creation of stable, sustainable configuration modules that enhance structural efficiency. The tessellated development utilises compression loads effectively, improving metal durability and providing protection against extreme climate and seismic forces. The architectural design highlights the integration of ecological and sustainable engineering principles, offering potential for future designs and improved housing quality.

The study results highlight the performance of the structural panels, including disphenoid, tetrahedral disphenoid honeycomb, convex uniform honeycomb, and tetrahedron configurations. Practical and theoretical design concerns emerged, particularly regarding cost implications and construction timelines. Engineers and architects need to address these concerns by consulting with geology and meteorology experts. Heavy loads, such as those from tornadic shear, may significantly impact the structural components. Effective construction involves careful application of materials and consideration of sustainability.

7. CONCLUSION

SISA is envisioned as a "Generic Building System and Technology," designed to create pioneering building components through a combination system using standard elements. SISA embodies the application of multiple configurations, permutations, and combinations in traditional metal building facades. It is advancing technological capabilities in various construction fields due to a new paradigm in building science. SISA offers surface articulation units for architects and engineers, promoting sustainability by adhering to circular principles of nature and optimizing the use of composite materials.

Research aimed at enhancing resource efficiency across industrial processes has highlighted the potential of SISA and material reuse. The system employs a systematic approach for integrating surface articulation, focusing on maximizing efficiency and profitability with unique stress on component use. Despite the extensive use of steel, smart glass, and other materials, the components of SISA work synergistically, allowing single-unit properties to handle distinct static and dynamic loads.

SISA has significantly contributed to the evolution of human-built environments. Various composites manufactured through multiple technologies have found broad applications. The SISA concept is applied in "new paradigm" research exploring high-rise construction without heavy concrete or steel and utilizing "Fractal Space Frame" structural systems alongside high-density, plant-derived foams and foamed glass fire protection.

SISA presents exceptional structural advantages, with its benefits increasing through experience. It offers immense satisfaction in various applications such as housing, factories, and bridges, especially under heavy and seismic loads. The lightweight and rigidity of the system contribute to its durability and resilience against seismic forces, making it ideal for seismic-prone areas. SISA's designs improve fire safety and sustainability, enhancing structural performance and offering a promising configuration for areas vulnerable to seismic and fire events.

The focus of SISA on using specific shapes is driven by efficiency and strength rather than strict form. The system’s lightweight and strength offer significant advantages, but the design process is complex and time-consuming. Technological advancements have improved the ability to create efficient systems, and designers must prioritize efficiency, constructability, and durability in their designs.

ACKNOWLEDGEMENTS

Feyza Nur Yildirim acknowledges the Republic of Türkiye Ministry of National Education for funding her MSc. The author is also grateful to architect Jude H. Johnston, who coined the term “SISA” and provided the illustrations.

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