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From the Editor

Dear Colleagues,

On behalf of the editorial board of International Journal of Engineering Technologies (IJET), I would like to share our happiness to publish the 30th issue of IJET. My special thanks are for members of Editorial Board, Publication Board, Editorial Team, Referees, Authors and other technical staff.

Please find the 30th issue of International Journal of Engineering Technologies at http://ijet.gelisim.edu.tr or https://dergipark.org.tr/en/pub/ijet. We invite you to review the Table of Contents by visiting our web site and review articles and items of interest. IJET will continue to publish high level scientific research papers in the field of Engineering Technologies as an international peer-reviewed scientific and academic journal of Istanbul Gelisim University.

Thanks for your continuing interest in our work,

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Mechanical and Physical Performance of Portland Cement Composites with Partial Replacements of Metakaolin and Ulexite

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Abstract- Fabricating green binding materials are gaining a great importance in the construction sector recently. This rising interest is based upon the need for more sustainable and environment-friendly alternatives to conventional cementitious materials by utilizing waste materials and mineral by-products in the binding matrices through partial or complete replacement with Portland cement. In this paper, an experimental investigation was conducted to examine the effect of using a boron waste, namely ulexite, along with metakaolin as partial replacements with Portland cement. By this means, flow table, setting time, compressive and flexural strengths, unit weight, water absorption, and porosity tests were carried out on twelve different specimens, including the amount of ulexite of 5% and 7%, metakaolin of 10% and 20%, and amount of superplasticizer additive of 1%. The main conclusions of this work showed that using ulexite and metakaolin up to certain percentages is beneficial in terms of mechanical and physical properties. A further increase in the addition can lead to a decrease in the performance of the matrix.

Keywords: Portland cement, Boron, Ulexite, Metakaolin, Superplasticizer

1. Introduction

Boron is an essentially valuable mineral that is used in many industries (nearly 500 fields), from technology and medicine to nuclear waste storage and space exploration, including material engineering and construction sectors such as cement [1,2], and its use is increasing day by day [3].

Boron does not exist by itself in nature. It exists as boric acid or borates (boron minerals) combined with oxygen and other elements [4]. Boron, which has several amorphous and six polymorphic allotropes, is considered the most rigid element after diamond [5]. The world's largest boron reserves are located in Turkey, the USA and Russia. However, Turkey possesses the most of the world's boron reservations by 72.1%. There are 230 different boron minerals in the nature. The most important ones are tincal, colemanite, ulexite, kernite, pandermite, szaybelite and hydroboracite in terms of commercial importance [6].

Boron usage in cement is limited due to hardening and other related problems worldwide. If these problems can be eliminated, the widespread use of boron compounds as additives in cement and concrete production would be possible. Thus, some technological developments will be added to cementitious composites, such as additional fire resistance and radiation impermeability [7,8].

Metakaolin

Metakaolin (MK) is produced by heating kaolinite (China clay) at (600-850) °C for 30–60 minutes. It has high pozzolanic activity. Therefore, it can replace cement because of its pozzolanic properties. The engineering properties of MK are controlled as it is not a by-product [9-11].

MK is a material that includes a high amount of SiO_2 and Al_2O_3. The silica and alumina in the structure of metakaolin form new calcium silicate hydrate (CSH) structures and alumina-containing phases (C4AH13, C2ASH8, C3AH6) by reacting with $Ca(OH)_2$ formed as a result of hydration of cement. Thanks to these comprised products, it increases mechanical properties and durability in cement and concrete produced [12,13].

Moreover, it was shown that MK replacement in cement could lower the normalized CO_2 emissions and resource consumption [14]. MK has to go through a burning process like cement, whereas the temperature of MK production is between 700 °C–900 °C as opposed to 1450 °C in cement production. Therefore, a significant amount of CO_2 emissions will be reduced by using MK. In terms of sustainability aspects, this feature can help MK use in concrete production in the future [11].

Boron Compound Usage in Cement

Until now, there have been some studies that different amounts of boron compounds are used in cement production and evaluated in terms of durability properties. Uğurlu et al. [15] investigated the effects of clay wastes containing boron compounds on the mechanical properties of mortar. They found that clay wastes that occurred during tincal production can be utilized in cement.

Targan et al. [16] added colemanite waste separately to the Kula slag and bentonite mixture. They stated that different proportions of colemanite waste could be used in cement production, and clinker production would achieve energy savings [16,17].

Boron compounds, especially colemanite, are used in the construction industry due to their durability-increasing, resistance to heat and radiation and isolation-providing properties. Moreover, it has been proved that cement with boron addition was more durable than Portland cement (PC) and had a low heat of hydration [17,18]. Concretes containing cement with boron are more impervious and durable to external factors. Also, these concretes' water absorption and chlorine permeability are 30% less than concretes, including PC [17].

In Anuk's study [18], the use of MK instead of cement increased the flexural and compressive strengths of the mortars and decreased the expansion values that may occur due to alkali-silica reaction (ASR), also decreasing the amount of water absorption and permeability. The highest compressive and flexural strengths were obtained using 15% MK in mortars. In addition, the lowest values of expansion, water absorption and permeability due to the effect of ASR and sulfate were observed in mortars containing 15% MK.

Ulexite

Ulexite is one of the important borates. Its chemical formula is $NaCaB_5O_9.8H_2O$. It is a boron mineral glassy, white or non-coloured, transparent to opaque, and soluble in water. According to the Mohs Hardness Scale, its hardness is 2.5, and its specific weight is 1.95–2 gr/cm. [19,21]

Ulexite, a mineral-rich type of boron, plays a significant role in heat, sound and radiation insulation, glass, ceramics and fertilizer industries and is also used in boric acid and borax production [18,22].

Although there are few studies on ulexite in building materials and the construction sector, some studies show that ulexite might be used in cement [23,24]. In this study, the mechanical properties of Portland cement with metakaolin and ulexite replacement have been investigated.

2. Materials and Methods

2.1. Materials

The materials used in this study are Portland cement CEM I 42.5 R, ulexite, metakaolin, superplasticizer, Rilem sand as fine aggregates and potable tap water. Characteristics of the materials are shown below:

Cement: Portland cement CEM I 42.5 R, manufactured by Adana Cement Industry, was used. In order to use fresh cement, all necessary measures were taken, and agglomeration was prevented by keeping the cement in special protective containers. The physical and chemical properties of the cement are presented in Table 1.

Table 1. Chemical and physical properties of cement (CEM I 42,5 R)

Chemical compounds	Results (%)
S_iO_2	19.55
Al_2O_3	5.31
Fe_2O_3	4.15
Mg_2O_3	0.06
CaO	62.30
MgO	3.14
SO_3	2.55
Na_2O	0.36
K_2O	0.88
Free CaO	0.31
LOI.	1.73
Specific density	3.10 g/cm^3

Ulexite: Dried ulexite ($Na_2O.2CaO.5B_2O_3.16H_2O$) from Eti Mine Bigadic Boron Works (Balikesir, Turkey) is used in this study. The physical and chemical properties of the ulexite are shown in Table 2.

Table 2. The chemical compound of ulexite (-45 μm)

Component	Content (%)
B_2O_3	37±1
CaO	19
SiO_2	≤4
Fe_2SO_3	≤0.04
Al_2O_3	≤0.25
MgO	≤2.50
SrO	≤1
Na_2O	≤3.50

Metakaolin: Metakaolin used in this study was obtained from Kaolin Endustriyel Mineraller Inc. (Istanbul, Turkey). Its chemical composition is presented in Table 3. Its mineralogical composition is quartz ~ 8, mica ~ 4, kaolinite – traces, amorphous phase ~ 87, and the others ~ 1).

Table 3. Chemical composition of metakaolin

Chemical Composition	Amount (%)
SiO_2	56.10
Al_2O_3	40.23
Fe_2O_3	0.85
SO_4	0.55
CaO	0.19
MgO	0.16
K_2O	0.51
Na_2O	0.24
LOI.	1.10

Superplasticizer: Polydos® TS 14 super plasticizing concrete admixture was used in this study. The recommended dosage of the chemical compound in the official description varies between 0.6 and 2.0 kg per 100 kg of the binder.

In this study, preliminary studies were conducted to estimate the optimal amount. It was found that the addition of 2% and 1.5% of Polydos® TS 14 by mass delayed the setting time too much. Following the results, it was observed that the most optimal amount of Polydos® TS 14 is 1% by the mass of the binder or 4.5 g.

Polydos® TS 14's technical properties are shown in Table 4.

Table 4. Technical properties of Polydos® TS 14

Technical properties	Description
Chemical contents	Polycarboxylate based
Appearance-colour	Brown liquid
Density	1.05±0.02 kg/L
pH value	4.5±1
Chloride content (Cl)	<0.1%
Alkali content	<4%
Freezing point	-4 ºC

Rilem sand: Standard Rilem sand produced by Trakya Cement Factory (Kırklareli, Turkey), matching the regulations stated in TSE EN-196, was used as fine aggregates while mixing the preparation.

Water: Potable tap water was used to prepare the blends and store the hardened samples.

2.2. Methods

This experimental study was conducted to determine the mechanical and physical performances of Portland Cement composites with partial replacements of metakaolin and ulexite.

This experimental study was conducted in Istanbul Gelisim University's building materials laboratory in 2022. Since this study does not contain any human or animal subjects, ethics committee approval is not applicable.

The specimens were divided into 12 groups according to their ingredients. One of the samples was the control group. Flow table, setting time, compressive and flexural strengths, unit weight, water absorption, and porosity tests were applied on all 12 specimens during 90 days with intervals of 2, 7, 28, and 90 days.

Necessary data were collected from the results of the experiments. The results were shared in the results section.

2.3. Preparation of the Samples

Twelve different samples were prepared with the replacement of ulexite of 5% and 7%, metakaolin of 10% and 20%, and the addition of a superplasticizer additive of 1%, in compliance with BS EN 196-1. The samples were organized for the tests of fresh and hardened properties separately and named based on their ingredients. The prepared samples were immersed in water on the second day of curing and kept at 20±2 ºC.

The amounts and percentages of the materials are stated in Tables 5 and 6.

Table 5. Percentage of materials in the blends

Mix ID	Cement (%)	Sand (%)	Ulexite (%)	Metakaolin (%)	W/C ratio	TS 14 (SP) (%)
Control	**100**	**100**	**0**	**0**	**0.5**	**0**
5UX	**95**	**100**	**5**	**0**	**0.5**	**0**
7UX	**93**	**100**	**7**	**0**	**0.5**	**0**
SP	**100**	**100**	**0**	**0**	**0.4**	**1**
5UX-SP	**95**	**100**	**5**	**0**	**0.4**	**1**
7UX-SP	**93**	**100**	**7**	**0**	**0.4**	**1**
MK20	**80**	**100**	**0**	**20**	**0.5**	**0**
MK30	**70**	**100**	**0**	**30**	**0.6**	**0**
MK20-SP	**80**	**100**	**0**	**20**	**0.5**	**1**
MK30-SP	**70**	**100**	**0**	**30**	**0.5**	**1**
5UX-MK20	**75**	**100**	**5**	**20**	**0.5**	**0**
5UX-MK30-SP	**75**	**100**	**5**	**20**	**0.5**	**1**

Table 6. Amount of materials in the blends

Mix ID	Cement (g)	Sand (g)	Ulexite (g)	Metakaolin (g)	Water (g)	TS 14 (SP) (g)
Control	**450**	**1350**	**0**	**0**	**225**	**0**
5UX	**428**	**1350**	**22.5**	**0**	**225**	**0**
7UX	**419**	**1350**	**31.5**	**0**	**225**	**0**
SP	**450**	**1350**	**0**	**0**	**203**	**4.5**
5UX-SP	**428**	**1350**	**22.5**	**0**	**203**	**4.5**
7UX-SP	**419**	**1350**	**31.5**	**0**	**203**	**4.5**
MK20	**360**	**1350**	**0**	**90**	**225**	**0**
MK30	**315**	**1350**	**0**	**135**	**270**	**0**
MK20-SP	**360**	**1350**	**0**	**90**	**225**	**4.5**
MK30-SP	**315**	**1350**	**0**	**135**	**225**	**4.5**
5UX-MK20	**338**	**1350**	**22.5**	**90**	**225**	**0**
5UX-MK30-SP	**293**	**1350**	**22.5**	**90**	**225**	**4.5**

2.4. Experiments

Following the preparation and curation of the samples, the flow table, setting time, compressive and flexural strengths, unit weight, water absorption, and porosity tests were conducted over 90 days with intervals of 2, 7, 28, and 90 days.

3. Results and Discussion

3.1. Flow Table Test

In order to demonstrate the spreading properties of the samples flow table test was applied to the fresh mortars.

It was seen that all samples behaved differently; the mixture MK20-SP showed a drastically good result when the control sample (PC) was taken as a reference. 7UX-SP, MK20-SP and 5UX-MK20-SP gave the closest values when it was compared to the control sample (Table 7).

Although adding 20% of metakaolin caused low flow ability, adding 1% of superplasticizer had very positive effects on the flow ability of the samples.

The test showed that the addition of ulexite reduces the spreading of the mortar, and metakaolin affects the spreading characteristics significantly, increases W/C up to 0.6, and facilitates flow ability.

The flow table results were compared with plain Portland cement mortar flow results, which was 17.75 cm spread. The comparison of 5UX-MK20-SP was approximately the same with PC or 0.5 (100.70%). Comparison percentages of the samples according to the control sample (PC) were presented on Tab.

Table 7. Flow table test results

Sample name	D_1 (cm)	D_2 (cm)	D_3 (cm)	D_4 (cm)	D_{avg} (cm)	D_0 (cm)	Results (%)
Control	17.5	18	18	17.5	17.75	10	77.5
5UX	12.5	12	12.5	12	12.25	10	22.5
7UX	15.5	16	15.5	16	15.75	10	57.5
SP	15	15.5	15.5	15.5	15.375	10	53.75
5UX-SP	15	15	15.5	15.5	15.25	10	52.5
7UX-SP	17.5	17.5	17.5	17.5	17.5	10	75
MK20	12.5	12	12	12.5	12.25	10	22.5
MK30	16.5	16	16	16	16.125	10	61.25
MK20-SP	17.5	17.5	18	18.5	17.875	10	78.75
MK30-SP	15.5	15.5	15	15	15.25	10	52.5
5UX-MK20	12	11.5	12	12	11.875	10	18.75
5UX-MK20-SP	16.5	17	17	16.5	16.75	10	67.5

Table 8. Flow table test results compared to the control sample

Sample name	Comparing to PC
Control	100%
5UX	69.01%
7UX	88.73%
SP	86.62%
5UX-SP	85.92%
7UX-SP	89.59%
MK20	69.01%
MK30	90.85%
MK20-SP	100.70%
MK30-SP	85.92%
5UX-MK20	66.90%
5UX-MK20-SP	94.37%

3.2. Setting Time

The samples' initial and final setting times were measured using the VICAT apparatus with a needle of ⌀1.3. The results were provided on Table 8.

The samples including ulexite gave longer setting time results, whereas the samples including metakaolin gave shorter setting time results. It could be inferred that the addition of ulexite prolonged and metakaolin shortened the setting time of the mortar.

Table 9. Setting time test results

Sample name	Setting time (min)
Control (PC)	**178.34**
5UX	**356.67**
7UX	**561.88**
SP	**230**
5UX-SP	**522.50**
7UX-SP	**944**
MK20	**118.75**
MK30	**207.50**
MK20-SP	**279.29**
MK30-SP	**218.34**
5UX-MK20	**276.43**
5UX-MK20-SP	**525.63**

3.3. Compressive Strength

Second, seventh, 28th and 90th-day compressive strength results were measured and noted. The results are shown in Table 9. The sample with ID 'SP' had the highest compressive strength values on the second, seventh, 28th and 90th days, 7UX-SP had the lowest compressive strength value on the second day, and 7UX had the lowest compressive strength value on the 7th, 28th and the 90th days.

Table 10. Compressive strength results (MPa)

Sample name	2-day	7-day	28-day	90-day
Control (PC)	**24.85**	**30.49**	**36.97**	**38.47**
5UX	**14.06**	**18.03**	**26.03**	**33.35**
7UX	**9.65**	**17.05**	**21.43**	**27.03**
SP	**25.45**	**42.46**	**44.20**	**46.72**
5UX-SP	**13.17**	**33.86**	**39.17**	**45.58**
7UX-SP	**0.00**	**26.36**	**40.14**	**40.87**
MK20	**16.63**	**33.65**	**34.54**	**46.54**
MK30	**20.18**	**22.31**	**26.46**	**36.59**
MK20-SP	**16.12**	**27.68**	**38.28**	**46.57**
MK30-SP	**14.16**	**26.18**	**40.49**	**44.53**
5UX-MK20	**10.19**	**29.15**	**33.81**	**45.17**
5UX-MK20-SP	**7.18**	**23.28**	**36.64**	**43.93**

It is calculated that the addition of 5% ulexite only by mass, or 22.5 g, decreases the compressive strength by approximately 40% on the 7th day, 30% on the 28th day, and 13% on the day 90th. Meanwhile, increasing ulexite proportion to %7 only, compressive strength decreased by approximately 44% on the 7th day, 42% on the 28th day, and 30% on the 90th day. It can be concluded that increasing ulexite by more than 5% decreases compressive strength drastically. This occurs due to the high calcium content of ulexite.

The addition of 1% Polydos® TS 14 increased compressive strength results as of the second day. Adding 1% Polydos® TS 14 superplasticizer and 5% ulexite increased compressive strength by approximately 11% on the 7th day, 5% on the 28th day, and 18% on the 90th day. However, its 2-day compressive strength was less than 53%. Moreover, when 7% of ulexite and 1% of Polydos® TS 14 superplasticizer were added, compressive strength results decreased compared to 5% of ulexite and 1% of SP and showed an increase when compared to the control sample. The results showed that the ideal amount for ulexite was 5%.

The samples that metakaolin was added showed low compressive strength results according to the control (PC) sample on the second day. However, their compressive strength results increased from the seventh day and gave higher results than the PC sample. The results showed that adding 30% of metakaolin led to the sample being more durable in a short time, nevertheless adding 20% of metakaolin gave more durable samples. In addition to that adding superplasticizer had positive effects.

Whereas ulexite and metakaolin were mixed the results showed that the samples became more durable in terms of compressive strength and they became more durable when a superplasticizer was added to the sample.

The changes in the samples day by day are shown in Figure 1

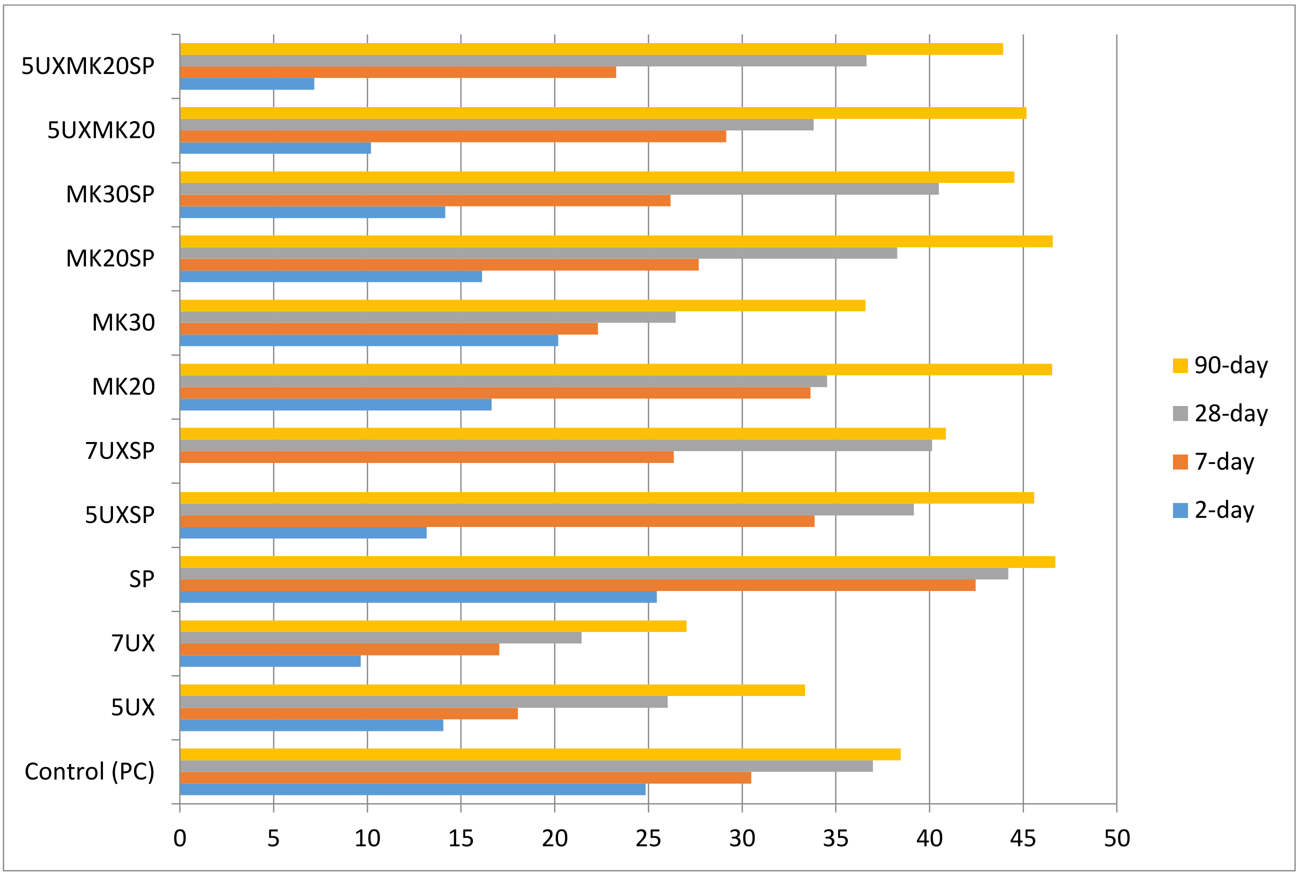

Figure 1. Comparison of compressive strength values as per 2nd, seventh, 28th and 90th days

3.4. Flexural Strength

Two, seven, 28- and 90-day flexural strength results were measured and noted. The results are shown in Table 10. SP sample had the highest flexural strength values on the 2nd, 7th and 28th days. However, MK30-SP had the highest flexural strength value on the 90th day. 7UX-SP had the lowest flexural strength value on the second day, and 7UX had the lowest flexural strength value on the 7th, 28th and 90th days.

Table 11. Flexural strength results (MPa)

Control (PC)	**5.95**	**7.10**	**8.03**	**8.57**
5UX	**3.72**	**5.31**	**6.19**	**7.25**
7UX	**2.62**	**4.30**	**6.13**	**6.12**
SP	**6.37**	**9.45**	**9.72**	**9.28**
5UX-SP	**3.78**	**7.49**	**7.76**	**8.78**
7UX-SP	**0.00**	**7.15**	**8.50**	**9.82**
MK20	**5.20**	**7.80**	**8.83**	**8.24**
MK30	**5.13**	**5.79**	**7.75**	**8.82**
MK20-SP	**4.86**	**7.67**	**8.71**	**9.02**
MK30-SP	**4.40**	**6.37**	**9.27**	**9.79**
5UX-MK20	**2.70**	**6.51**	**9.41**	**9.47**
5UX-MK20-SP	**2.30**	**5.90**	**9.34**	**8.99**

Flexural strength results of the samples 5UX and 7UX, which were obtained by mixing plain Portland cement with UX in the proportions of 5% and 7%, displayed lower than PC for 90 days. On the other hand, the sample mixed with only 1% Polydos® TS 14 showed a higher result than the control sample during 90 days. The samples created by adding ulexite and superplasticizer (5UX-SP and 7UX-SP) eliminated the adverse conditions and showed higher results than the control sample (PC) as of the 7th day. Moreover, the addition of MK gave similar results to the control sample. However, adding 30% of MK prolonged the flexural strength results slightly. Nevertheless, the samples with MK addition exhibited slightly higher results on the 90th day than the control (PC) sample.

It was observed that as the amount of added UX increased, the setting time increased and therefore the flexural strength results were poorer than the control sample. When 1% SP was included in the samples, it was seen that the results were healed. Also, although adding 30% MK had already slightly better results compared to the control sample, adding 1% superplasticizer healed the results and led to give better results. In these cases, it is clear that the addition of SP removes the negative effects.

The best results of the samples according to the days; SP (1% Polydos® TS 14 superplasticizer) with 6.37 MPa on the 2nd day, SP with 9.45 MPa on the 7th day, SP with 9.72 MPa on the 28th day and MK30-SP (30% MK and 1% Polydos® TS 14 superplasticizer) with 9.79 MPa on the 90th day. According to the results, it can be concluded that adding superplasticizer had positive effects on the samples.

The changes in the samples day by day are shown in Figure 2.

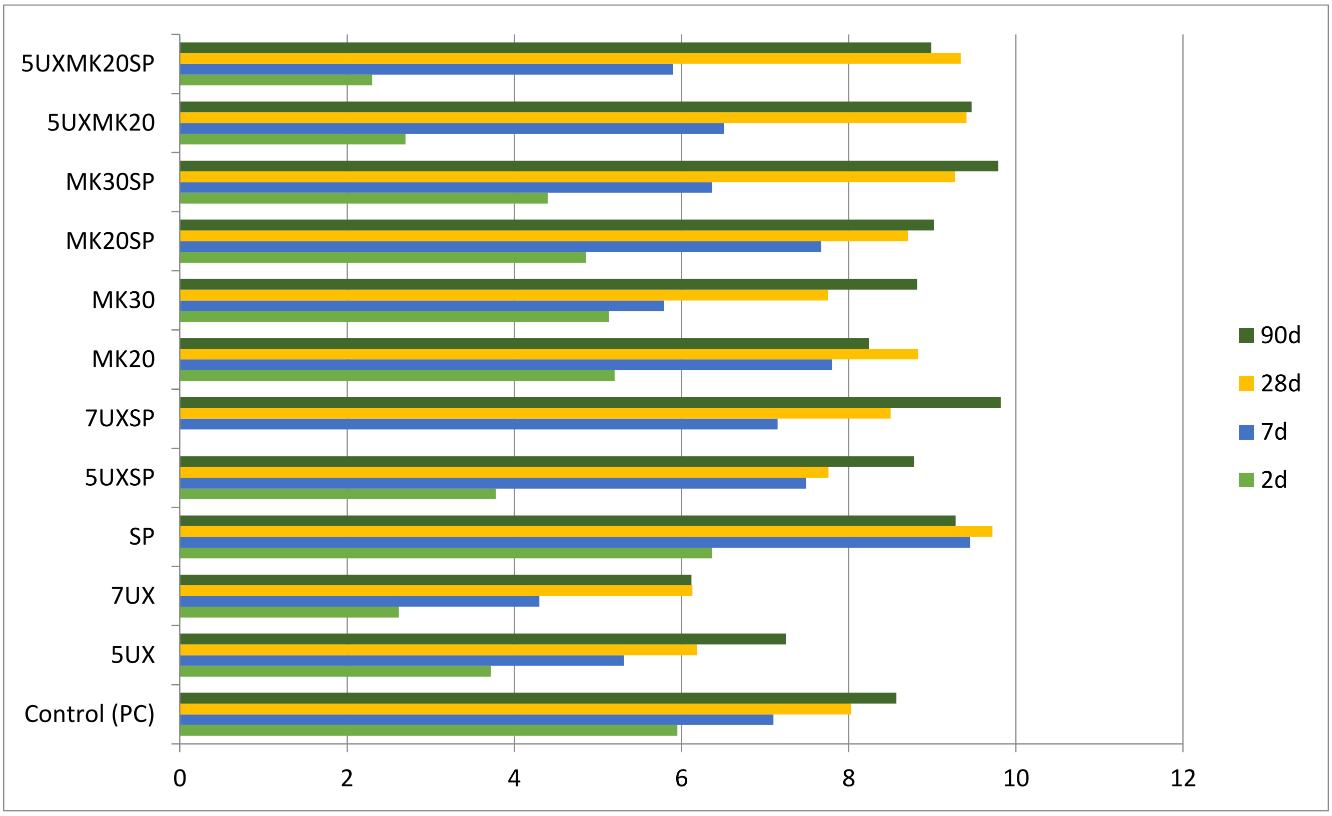

Figure 2. Comparison of flexural strength values as per 2nd, seventh, 28th and 90th days

3.5. Unit Weight

All samples' unit weights were measured. The results were presented on Table 11. According to the obtained results, 5UX-MK20 had the lightest unit weight with 2.295 g/cm^3 (3.81% higher than PC), and 7UX had the heaviest unit weight with 2.437 g/cm^3 (2.14% heavier than PC). The slight reduction in the densities of MK and UX samples was due to the changing specific gravity of MK and UX compared to cement alone.

Table 12. Unit weight test results

Sample name	Unit weight (g/cm^3)
Control	2.386
5UX	2.392
7UX	2.437
SP	2.428
5UX-SP	2.393
7UX-SP	2.396
MK20	2.367
MK30	2.309
MK20-SP	2.360
MK30-SP	2.302
5UX-MK20	2.289
5UX-MK20-SP	2.295

3.6. Water Absorption

A water absorption test WAS conducted for all 12 samples, and the change between wet and dry weights was presented on Table 12. According to the test, 7UX had the highest water absorption capacity (7.892%), and MK30-SP (3.419%) had the lowest absorption capacity, respectively.

Table 13. Water absorption test results

Sample name	Water absorption (%)
Control	**6.524**
5UX	**7.508**
7UX	**8.892**
SP	**5.161**
5UX-SP	**5.701**
7UX-SP	**5.253**
MK20	**6.237**
MK30	**5.846**
MK20-SP	**4.942**
MK30-SP	**3.419**
5UX-MK20	**5.691**
5UX-MK20-SP	**5.507**

UX has more water absorption capacity when it's compared to MK, and SP reduces water absorption via water demand reducer chemicals. It was seen that increasing water absorption leads to negative effects in terms of durability when the compressive and flexural strengths and water absorption capacity are assessed together.

3.7. Porosity

The results of the porosity test conducted are shown in Table 13. The given percentages represent the ratio between dry weight, wet weight and Archimedes' weight. The porosity results were provided on Table 13.

Only the samples including the replacement of only 5% and 7% of ulexite gave higher results compared to the control sample. Other samples gave higher porosity results. It can be concluded that ulexite increases and metakaolin decrease the porosity of the cement. Additionally, adding SP decreases porosity.

Table 14. Porosity test results (%)

Sample name	**Porosity**
Control (PC)	**13.425**
5UX	**15.231**
7UX	**16.129**
SP	**11.143**
5UX-SP	**12.110**
7UX-SP	**11.189**
MK20	**12.831**
MK30	**11.865**
MK20-SP	**11.572**
MK30-SP	**7.314**
5UX-MK20	**11.952**
5UX-MK20-SP	**11.228**

3.8. Effect of Water/Cement Ratio

In order to estimate the required amount of water, sample series were prepared and in these series water/cement (W/C) ratio changed between 0.4 and 0.6. The W/C ratio was increased in some samples due to hard mixing and compaction.

In this study, three types of W/C ratios were used. These were 0.6 (high), 0.5 (average) and low (0.4), which are more typically used. High W/C ratio for MK30. average W/C ratio for the samples control (PC), 5UX, 7UX, MK20, MK20-SP, MK30-SP, 5UX-MK20 and 5UX-MK20-SP in acceptable margins. Furthermore, due to their extreme fluidity, for the samples, SP, 5UX-SP and 7UX-SP low W/C ratio was used.

Table 15. W/C ratios of the samples

Sample name	**W/C ratio**
Control (PC)	**0.5**
5UX	**0.5**
7UX	**0.5**
SP	**0.4**
5UX-SP	**0.4**
7UX-SP	**0.4**
MK20	**0.5**
MK30	**0.6**
MK20-SP	**0.5**
MK30-SP	**0.5**
5UX-MK20	**0.5**
5UX-MK20-SP	**0.5**

The samples with the low W/C ratio had the best results. However, the compressive and flexural strength results showed that the W/C ratio data are not sufficient to determine the effect of the W/C ratio on durability. To conclude, the W/C ratios of the samples should be increased and all three ratios should be used for every sample.

4. Conclusion

The flow table test showed that blending only ulexite in 5% and 7% proportions decreased the workability of the fresh mortars. However, the inclusion of Polydos® TS 14 superplasticizer solves this problem and increases the workability. Likewise, mixes containing MK only in 20% and 30% showed low workability, and the problem was solved by adding Polydos® TS 14 superplasticizer.

The addition of ulexite only prolonged the mortar's setting time. The addition of only 5% of ulexite extended the setting time to 2.97 hours, and the addition of only 7% of ulexite extended 6.40 hours. The addition of Polydos® TS 14 superplasticizer to the 5% and 7% ulexite-only samples extended the setting time to 5.74 hours and 12.75 hours, respectively. It might be caused due to increasing percentage of %B_2O_3 with ulexite. It is known that a high concentration of %B_2O_3 causes retarding in setting time and decreasing in compressive strength.

MK facilitates early hardening depending on the W/C ratio. Using MK only in 20% and 30% proportion helps mortar gain flexural strength close to the control sample's value. However, adding 20% MK helps the mortar gain higher compressive strength than the control sample. Also, the addition of Polydos® TS 14 superplasticizer helps the mortars to improve their strength results.

An increase in the amount of ulexite leads to a proportional increase in unit weight, porosity and water absorption characteristics.

Adding a superplasticizer decreases the porosity of the hardened mortars. It is shown that, with the decrease in porosity, the durability of the cement increases.

Water absorption also decreases with the addition of a superplasticizer. It is shown that the more water absorption in the samples gives the less durability. They have inverse proportions. Furthermore, the water absorption results are not a reliable parameter for concrete durability estimation.

In conclusion, UX should not be used in mortar only. If it will be used, an additional chemical such as Polydos® TS 14 superplasticizer could be used. The superplasticizer amount cannot exceed 1% in providing a mixture within a reasonable time. Also, additional compounds such as MK should be used with UX. The percentage of MK should not exceed 30%. If it will be higher than that, the W/C ratio should also be increased. Otherwise, flocculation will increase and workability will decrease. In the literature, the replacement of MK by 30% gives promising results. This supports our study. However, due to the large gap in the amount of MK in this study, further studies should be carried out on a more detailed assessment. An additional study may be carried out to include the other experiments such as freezing-thawing, acid and sulphate attacks, alkali-silica reaction tests and hydration heat measurements which were not included in this study.

Moreover, since there is not sufficient data on UX replacement in cement, further studies should be conducted in order to obtain more detailed information.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Waste Glass “An Alternative of Cement and Fine Aggregate in Concrete”

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Abstract - The major aim of this study is to use Waste Glass Powder (WGP) which is obtained from grinding glass waste using an abrasion apparatus, as cement and a fine aggregate substitute in concrete. The physical and mechanical characteristics, workability, and compressive strength of concrete were studied by using WGP as cement and fine aggregate replacement simultaneously. In order to perform correctly, the glass has to be sieved to particle sizes of less than 150 μm sieve for cement replacement and 4.75 mm for fine aggregate replacement. WGP was used to replace the cement and fine aggregate in concrete, yielding products with respective cement contents of 10.0% and 15% and fine aggregate contents of 15.0% and 20%, and the properties of this concrete have been compared with reference specimens with zero replacement. Cube specimens were cast, cured, and tested for compressive strength and workability at 7, 14, 28, and 56 days of age, and the results were then compared to those of traditional concrete. The use of WGP as a cement and fine aggregate substitute resulted in a reduction in concrete's compressive strength and workability. However, the findings revealed that WGP could be used as a partial substitute for cement and fine aggregates, with 10 to 15% of cement and fine aggregate substitution by WGP being the optimum in terms of strength and economy. As a result, we can utilize it in structures that are moderately heavy.

Keywords: WGP, Compressive strength, Waste management, Workability, Concrete, Cement, Fine aggregate

1. Introduction

In the building sector, concrete is a common material. It is composed of cement, coarse aggregate, fine aggregate, and water, with an admixture occasionally applied to accomplish desired results. Aggregate makes up 70% – 75% of the total volume of concrete. Cement, being a binding material and a crucial element of concrete, makes up a 7–15% portion of it [1]. It is estimated that the global production rate of concrete is about one ton per person per year and that this rate is continuously rising [2]. Being an energy-intensive industry, the cement industry's contribution to CO_2 emissions is 5% globally [3]. Depending on the type of fuel used, one ton of cement is expected to produce 0.9 to 1 ton of CO_2. The largest environmental worry of today, according to scientists, is man-made climate change as a result of global warming, which is the outcome of continuous and constant rising concentrations of greenhouse gases, notably CO_2, in the earth's atmosphere over the past 100 years [4]. Even though fine natural aggregates currently outperform all other resources in the production of concrete, their supply is quickly declining due to deliberate overexploitation brought on by rising urbanization and the development of other utilities worldwide. River fine aggregate depletes natural resources, lowers the water table, causes bridge piers to sink, and causes river bed erosion when used as a fine aggregate. If a particular percentage of fine aggregate is substituted with waste glass in a predetermined size range, the fine aggregate content will be lowered, reducing the detrimental impacts of river dredging and improving the sustainability of the concrete production sector [5]. The cement and concrete industries are using more and more solid industrial byproducts, such as siliceous and aluminous materials, as well as some pozzolanic minerals to mitigate such environmentally depleting circumstances. Concrete production could be made greener by using supplementary cementitious materials (SCMs), recovered aggregates, and other industrial wastes [6]. Supplementary cementitious elements are frequently used in concrete mixes to lower cement content, enhance workability, increase strength, and extend the concrete's life [7]. Waste glass powder is pozzolanic and can be utilized as a cementitious material with proper processing. The adequate replacement level of WGP is 10% for cement in concrete [8]. In the same manner, the optimal replacement of fine aggregate by waste glass was found to be 10% [9]. In order to manufacture cement, four basic materials are required. Lime (CaO), silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3) are among them. The chemical combination of these basic ingredients in the kiln, as well as the interaction that happens, produces the four primary compounds found in cement (known as calcination). Glass is a useful member of the garbage family in many rural and urban areas, and it is made up of a variety of inorganic raw materials that are processed into a stable, inert, hard, homogenous, amorphous, and isotropic material [10]. Due to its non-decomposable nature, waste glass usually doesn't have a negative impact on the environment, but if disposed of inappropriately, it can harm both humans and animals. The tremendous amount of waste glass is a challenge for the world now, with millions of tons of glass trash produced every year in the world. Glass accounts for 0.7 percent of the total urban garbage created in India. [11]. Every year, the United Kingdom produces about three million tons of waste glass. [12]. Because it is non-biodegradable, it takes up a lot of space in landfills and poses serious environmental risks [13]. WGP is a fine, superfine, or powdered glass made from waste glass collected from landfills, dumpsites, and other waste disposal sites. Waste glass is washed, crushed, ground, and milled to produce a fine powder. The amount of silicon and calcium in glass is relatively high.

In this study, cement and fine aggregate were partially substituted by waste glass at a rate of 10% & 15% and 15% & 20% by weight, respectively. For varying waste glass percentages, concrete specimens were evaluated for compressive strength and workability. When the results of the concrete mix containing 10% and 15% waste glass as cement and fine aggregate were compared to the results of a standard M-30 concrete mix, it was discovered that the compressive strength of the concrete mix containing 10% and 15% waste glass as cement and fine aggregate was comparable. Slump value declined as waste glass content increased, making concrete less workable. This study reviewed the behavior of concrete in which waste glass was utilized to replace cement and fine aggregate in proportions of 10%, & 15%, and 15% & 20% by weight, respectively, which may help to relieve waste disposal concerns while also improving the qualities of the concrete.

2. Research Significance

Due to its non-biodegradable nature, non-recyclable waste glass is a significant burden on landfills. Because of its non-decomposable nature and the scarcity of landfills in metropolitan areas, its disposal is considered a major concern. It is critical to determine the suitability of glass waste as an alternative cement and fine aggregate in concrete for these studies to persuade people that glass trash can be reused in the construction process. The test must be analyzed in order to determine whether the outcome meets the requirements or not. Because the test results will demonstrate whether glass waste can meet the minimal requirements for both physical and mechanical properties, this is the case. In this regard, the concrete and cement industries provide a better solution for glass waste, because of their identical physical properties and chemical composition to fine aggregate and cement. On one side, it will safeguard the environment, and on the other, it will conserve natural resources and save the economy. If waste glasses are utilized in the production of concrete goods, the cost of concrete production will be lowered [14]. Waste glass can be used to replace cement and fine aggregate to some extent in the manufacturing of concrete. Fine aggregate content will be reduced if waste glass is substituted in a particular proportion and in a specific size range, decreasing river dredging's harmful consequences and making the concrete manufacturing business more sustainable. Because of its pozzolanic tendency, it is a highly recommended alternative to cement in the making of concrete.

3. Materials and Methods

3.1. Materials Used

The laboratory experiments were carried out using the following materials:

3.1.1. Cement

Cement plays an important role in the production of concrete; as a binding agent, it holds together the aggregates in concrete. Ordinary Portland cement of 53R grade conforming to PS 232:2008 (R) was used throughout the work.

Table 1: *Chemical Analysis of Cement*

Test	Amount (%)
SiO_2	19.03
Al_2O_3	4.72
Fe_2O_3	3.556
CaO	61.08
MgO	2.67
K_2O	0.92
Na_2O	0.05
SO_3	2.89
Cl	0.001

The characteristics of concrete are greatly influenced by the amount of cement compound present. In general, there are five different types of cement. Their various qualities are a result of their compounds' various composition ratios, which have various hydration properties. For instance, a high belite percentage in cement types 2 and 4 results in low initial hydration heat and high long-term strength; a high aluminate ratio in type 3 results in a high initial strength.

Table 2: *Physical Tests Result of Cement*

Name of Test	Unit	Result Obtained
Fineness	m^2/kg	312
Consistency	%	27.54
Le-chetlier Expansion	mm	1.21
Auto Clave Expansion	%	0.07
Initial Setting Time	minutes	173
Final Setting Time	minutes	224

Table 3: *Compressive Strength Test Result of Cement*

Period	Result Obtained (MPa)
3 Days	36.56
7 Days	46.13
28 Days	55.25

3.1.2. Coarse Aggregate

Inert granular aggregates that make up 60 to 75 percent of overall concrete production are referred to as gravel. Gravel is made up of particles that are larger than 4.74 mm but usually fall between 9.5 and 37.5 mm. Locally available crushed coarse aggregate having a maximum size of 20 mm is used. The following laboratory tests were conducted on coarse aggregate.

Table 4: *Lab Test Result Conducted on Gravel*

Name of Test	Unit	Result Obtained	Standard
Aggregate Impact Value Test	%	16.57	BS812: part 112: 1990
Aggregate Crushing Value Test	%	15.6	BS812: part 110: 1990
Los Angeles Abrasion Value Test	%	33.32	ASTM C131 − 89
Rodded Bulk Density	gr/cm^3	1.57	BS812: part 2: 1975 OR ASTM C29 − 91a
Loose Bulk Density	gr/cm^3	1.40	BS812: part 2: 1975 OR ASTM C29 − 91a
SSD Specific Gravity	−	2.691	ASTM C127 − 93
OD Specific Gravity	−	2.668	ASTM C127 − 93
Water Absorption	%	0.8	-

3.1.3. Fine Aggregate

In the entire project, fine river aggregate conforming to grading zone 1 and passing through a 4.75 mm sieve and containing 75 microns was employed. The following tests were performed using ASTM standards.

Table 5: *Lab Test Result of Fine Aggregate*

Test	Unit	Result	Standard
SSD Specific Gravity	-	2.41	ASTM C128 − 93
OD Specific Gravity	-	2.365	ASTM C128 − 93
Fineness Modulus	-	3	ASTM C136 − 92
Grading Zone	-	1	-
Water Absorption	%	2.3%	-

3.1.4. Water

During concrete casting and curing, potable water is used. It was found behind the Laboratory Building of Alfalah University's Civil Engineering Department in Nangarhar, Afghanistan.

3.1.5. Glass Powder

The waste glass came from the dumpsites of glass selling shops. In order to obtain WGP, waste glass was cleaned with water to remove soil and other pollutants. The glass was then left to dry naturally. It was then pulverized in a Los Angeles abrasion apparatus until the particles were small enough to pass through a No. 100 sieve, achieving cement grading, and added to concrete to increase its strength. Waste glass was found to have a specific gravity of 2.42. The different percentages of cement replaced by glass powder were 10, and 15% respectively. It was also pulverized to obtain particle sizes ranging from 4.75 mm to 0.075 mm for grading fine aggregate. In the trials, the different percentages of fine aggregate replaced with glass powder were 15% and 20%. The chemical makeup of glass is shown in the table below.

Table 6: *Chemical Composition of Glass*

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
Percentage	71.2	1.6	0.8	9.8	2.9	13.4	0.3

Glass can be produced using thousands of distinct chemical combinations. The mechanical, electrical, chemical, optical, and thermal properties of the manufactured glasses are influenced by various formulations. Glasses don't all have the same chemical make-up. Here, we have utilized a common, contemporary soda-lime silica glass (used to make bottles and windows).

Figure 1: *Obtained broken waste glass*

Figure 2: *Sieved glass powder for cement and sand*

3.2. Methods

A mix ratio of 1:1.98:2.29 (Cementitious material: Fine aggregate: Coarse aggregate) was used in casting concrete cubes to achieve the desired concrete for the control mix.

Table 7: *Mix Proportion for Control Sample*

Cement	Fine aggregate	Coarse aggregate	Water/Cement Ratio
1	1.98	2.29	0.45

Natural fine and coarse aggregate were procured after the ingredients for manufacturing the design concrete mix of M-30 grade were obtained. The proportions established in the design mix were used to cast concrete cubes in sufficient numbers. A 0.45 water-to-cement ratio was chosen. The resulting waste glass was used to replace 10% and 15% by weight of cement content and 15% and 20% by weight of fine aggregate, respectively. In order to explore the impact of GP on concrete consistency, slump tests were utilized to assess the workability of various replacement-level concrete mixes. The concrete cubes were cured for 7, 14, 28, and 56 days. For each replacement level, twelve cubes were formed for 7, 14, 28, and 56 days to assess the compressive strength. Iron cube molds with dimensions of $150 \times 150 \times 150$ mm were used for concrete cubes.

Table 8: *Mix Proportion for Prepared Samples*

Mix type	Water/Cement	Cementitious materials (kg/m^3)		Water (kg/m^3)	Fine Aggregate (kg/m^3)		Coarse Aggregate (kg/m^3)
		OPC	WGP		Fine aggregate	WG	
Control	0.45	411.11	0	185	816.89	0	942
Trial 1	0.45	369.99	41.11	185	694.35	122.54	942
Trial 2	0.45	349.44	61.66	185	653.51	253.38	942

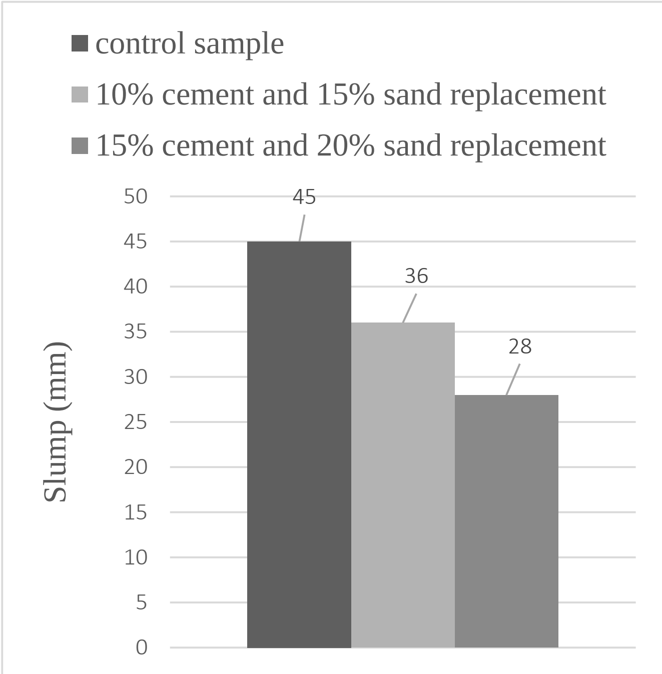

Figure 3: *Comparison of slump values of control, trial 1 and trial 2.*

4. Results and Discussions

4.1. Workability

The slump test was carried out in accordance with ASTM C143. The value is presented in the figure below.

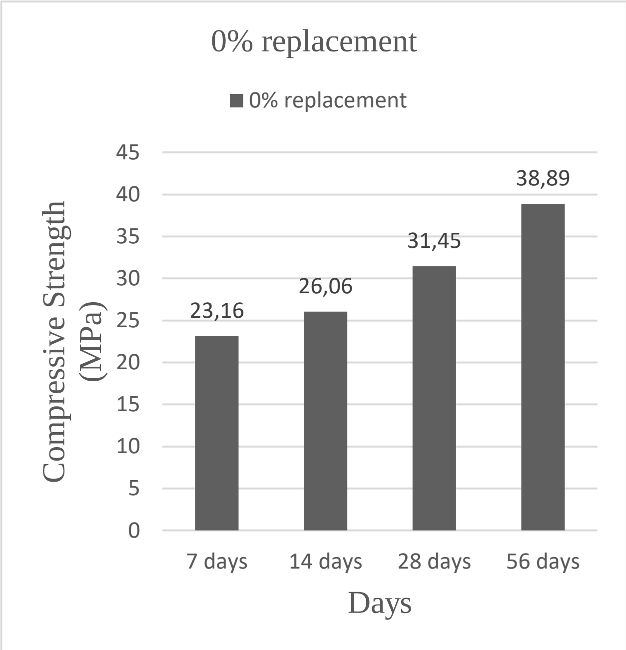

Figure 4: *Compressive strength of control sample*

The results demonstrate the slump value reduces as the amount of glass powder utilized increases. The fact that slump decreases as WGP content in concrete increases suggests that WGP-containing concrete is less workable than plain concrete. The angular form of glass powder particles is associated with slump minimization. Furthermore, glass powder in concrete has a higher density than cement and fine aggregate. Because glass powder is not cementitious in and of itself, using too much of it decreases the binding characteristics of fresh concrete, making it difficult to work with and compact.

4.2. Compressive strength

The concrete's compressive strength when WGP is used in place of cement and fine aggregate is shown in the figures below.

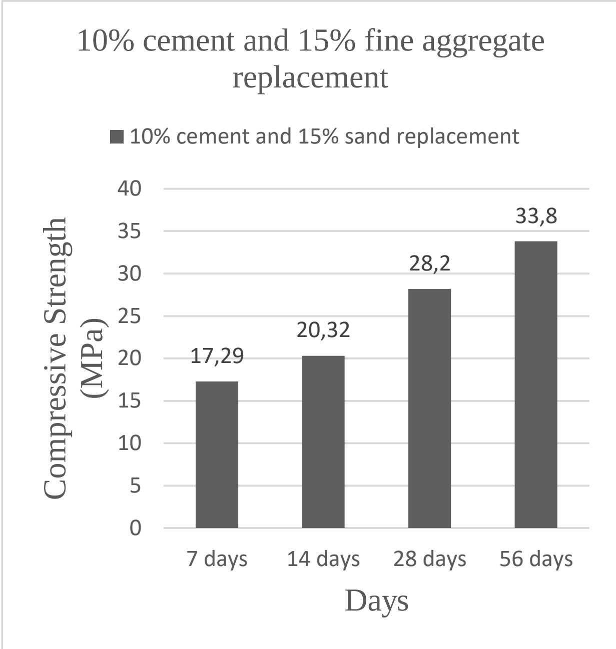

Figure 5*: Compressive strength of trial 1*

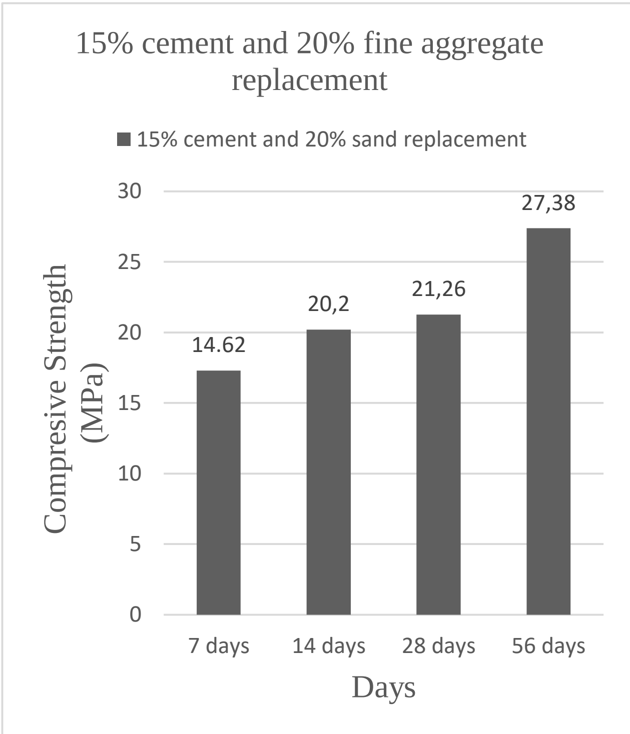

Figure 6*: Compressive strength of trial 2*

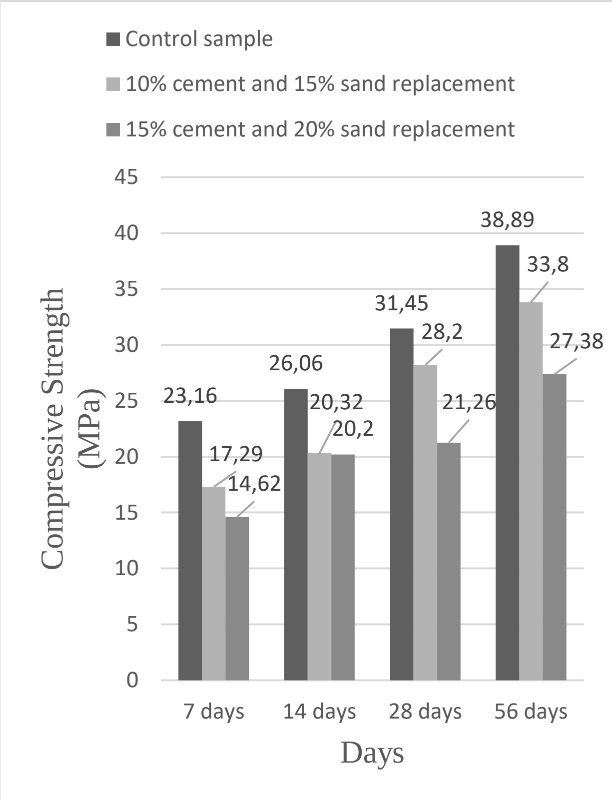

Figure 7*: Compressive strength of comparison*

The control mix's strength was 31.45 MPa after 28 days, greatly exceeding the minimum cube crushing strength of 30 MPa. Trial 1 indicated an exceptional strength value of 28.2 MPa, which was practically the target strength, despite the fact that mixes containing WGP did not meet the needed 28-day strength. Because pozzolanic effects would not be noticeable in such short durations, the drop in 28-day strength is likely to be a short-term effect, as evidenced in the 56-day result, where Trial 1 exceeded the goal of 28-day strength and Trial 2 almost achieved the target strength.

The concrete samples for the control as well as each replacement level gained strength as the curing time rose, as expected, despite the influence of glass powder content on the mixes. The compressive strength at 14 and 28 days in Trial 2 shows just a modest rate of strength development when compared to the rate of strength gain in Trial 1. The maximum percentages of WGP that can be used to replace both cement and fine aggregate at once are 10% and 15%, respectively.

5. Conclusions

The following conclusions can be drawn based on the results obtained:

1. WGP has the potential to be pozzolanic and can be used as a cementitious material with proper preparation.
2. As the percentage of replacement increases, the workability of concrete reduces.
3. There is a marginal decrease in slump for the first trial compared to the control sample.
4. The strength of concrete can be improved with a long curing time.
5. Compared to the control sample, there is a deficiency of only 10.33% at 28 days and 13.1% at 56 days for trial 1 in compressive strength, thus making it an optimal replacement level. This indicates that concrete with appropriate characteristics was produced when cement was replaced with WGP and fine aggregate with glass sand. In light of the strength requirements, WGP can replace cement up to 10% and glass sand can replace fine aggregate up to 15%.

Future Scope

This research is focused on the properties and strength behavior of concrete if WGP is used as cement and fine aggregate in concrete simultaneously. However, further studies are required on the following issues:

- The effect of WGP in concrete by keeping the replacement level constant and changing the size parameter.
- The effects of using WGP as a cement substitute and demolished brick waste as a fine aggregate substitute in concrete production at the same time.
- At the same time, the impact of using WGP as fine aggregate and demolished brick waste as replacement for coarse aggregate in the manufacture of concrete.

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Proposed Framework for Daylight-Focused Homes during Design Development

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Abstract - Solar decathlon is held biannually, and participant universities have a unique chance to locate solar houses on campus as a living lab after the contest. A variety of performance criteria are evaluated during the contest and daylighting is one among them. Complicated analysis tools, design solutions, and their effectiveness are major challenges during the design development of new solar houses. This challenge definition leads to developing a daylighting guideline for new solar house design. To provide a roadmap of validity of emerging daylighting metrics, demonstration of the daylighting performance of built-up solar houses, and daylighting guideline for design parameters with recent technology on new solar house design are the specific objectives of this study. The manuscript aims to examine the existing daylighting design tools while proposing a roadmap for how to use emerging metrics over solar house design. Three solar decathlon entries of Missouri University of Science and Technology are selected for post-occupancy evaluation to verify selected design tools. After analyze method, tools and final products are introduced which can be used on case studies, impact on research and education is discussed in the paper. Experiential method proposal for daylighting design have three phases and these are; the daylight metrics, the daylight performance and impact on research and education. It would be beneficial in the future to have this as a design guide, especially for any residential buildings rather than just solar houses.

Keywords: Solar House, Daylighting, Design Tools, Performance Measurement

1. Introduction

The proper daylighting design optimizes the use of natural light in order to reduce lighting energy costs and maximize the visual comfort of the indoor environment [1] [2] [3] [4]. A well-daylit building can provide significant energy reductions and reduced operating costs for building owners of not only new construction projects but existing facilities. A well-designed day-lit building is estimated to reduce lighting energy use by 50% to 80% but must evaluate and balance the impacts of heat gain/loss and glare control [5] [6]. In addition to energy efficiency, a well-daylit building allows for the occupants to have an enhanced level of visual acuity, along with an overall increased psychological, and biological well-being and productivity [7]. Five definitions can be used to define what daylighting is; architectural and visual, lighting energy savings, reduced energy consumption, load management, and cost optimization [8]. Daylight has become directly associated with human health, life comfort, and effectiveness at work [9] [10] [11]. Glare, or excessive brightness contrast within the field of view, is one aspect of lighting that can cause discomfort to the occupants of a space [12]. To balance occupant comfort and energy concerns, the amount of daylight should neither be too low nor excessive [3]. In poor visual comfort conditions, a person can experience distracting symptoms such as red and itchy eyes, headache or back pain associated with bad posture trying to compensate for uncomfortable illumination [4].

Many different tools are available today for daylight analysis. These tools range from simple methods such as the use of sun path diagrams, daylight factor charts, and simple rules of thumb to advanced methods such as software packages of varying degrees of accuracy and physical model studies with artificial skies and/or heliodons [3]. The intention is not to compare and judge tools against each other, but rather to provide a resource for researchers who are interested to learn more and/ or need to make a choice about tools for solar design [13].

This paper targets to examine daylight-focused solar house design by using emerging metrics and propose a framework for based-on this study. The paper split up in three steps to come with a solution through proposing a framework.

Hypothesis, aim and content of this study is introduced in second part; daylight-focused solar house design. Based-on this framework, an experiential method with different steps is proposed in third section. These phases are defined as following; the daylight metrics, the daylight performance and impact on research and education.

2. Daylight-Focused Solar House Design

Smart living is a trendy technological development in building science based on primarily energy efficiency, human health, and well-being. Creating a controlled indoor environment for occupants is a major concern in this research field. Daylighting is one of these aspects in terms of visual comfort, human health and well-being, and building energy efficiency. The concern about daylighting is not new, dating back to ancient times. Advances both in predictive modeling as well as advanced techniques have emerged in an attempt to effectively improve daylighting integration. The use of these tools provides rapid and accurate prediction methods. There are two main problems related to daylighting in a smart building; 1) the complexity of emerging metrics resulting in slow adaptation within the building community and, 2) the hardship over monitoring the effectiveness of daylighting design solutions in custom design homes. Consequently, the problem is narrowed and defined in the intersection among three parameters as a design solution, effectiveness, and analysis methods (Figure 1). Computer simulation, physical model analysis, and post-occupancy assessment will provide the necessary data to evaluate the daylighting performance of a building during design development. The challenge definition is set in a triangle focused on daylighting. The relationship of the challenge to sustainability can be described as the following: contribution to pollution prevention or control, facilitating building energy efficiency and environmental sustainability, bridge building sustainability to human health and well-being, and benefit the healthcare industry and the smart building system market.

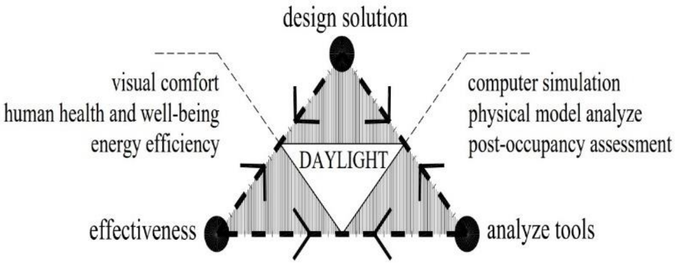


Figure 1: Challenge definition for the proposed system

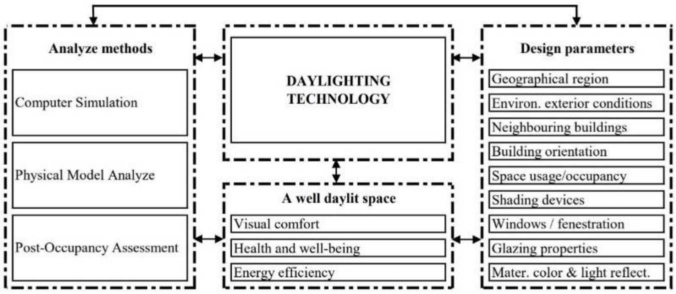
Solar decathlon is performed once in two years in the US, and it has both research and educational contribution to energy-efficient home design. These efforts can be split up into two; the first one is previously completed solar houses that have tenants inside that need post-occupancy evaluation. Qualitative and quantitative measurements can be performed by using different methodologies to assess the daylighting effect on visual comfort, well-being, and energy performance. The second one is ongoing design development for the upcoming solar decathlon. It is important to note that, a roadmap or a guideline of daylighting design answers to frequently asked questions during solar house design based on previous experiences would be beneficial to improve daylighting features of new solar houses prepared for the upcoming decathlon.

The hypothesis of this paper is "current and emerging metrics for daylight analysis tools can aid solar house design to provide better daylight performance during design development". According to the mentioned hypothesis, the purpose of this paper is to evaluate the usability of daylighting metrics during design development from the architectural engineering's point of view.

The research aims to investigate, develop, and deploy a daylighting model for sustainable and healthy indoor environments. The goal of this research is "saving a piece of the world by integrating daylighting through the use of emerging metrics in our buildings". The specific objectives are to complete the following: 1) validity of emerging daylighting metrics, 2) demonstration of the daylighting performance of solar houses, and 3) daylighting guideline for design parameters with recent technology on new solar energy house design.

This proposed daylighting model provides the performance parameters for a good daylight space in solar houses. With the help of emerging daylighting metrics, this project will measure primary design factors/parameters that directly affect indoor environmental quality. Design parameters related with the exterior environment are geographical region, natural and built environmental exterior conditions, neighboring buildings and building orientation. Others such as; space usage, shading device, window, glazing properties, material color and light reflectance are related with interior parameters. These design parameters can be measured utilizing analysis tools and these tools can be grouped into three categories: computer simulation, physical scaled model analysis, and post-occupancy assessment. The framework (Table 1) illustrates how each section of daylighting technology interacts and performs.

Table 1: Framework of the proposed system



3. Experiential Method Proposal for Daylighting Design

Analyze tools as daylighting metrics help design development of solar house. To do that, a complex analyze methods shall be performed in a sequence. Based-on specific objective of this paper, three analyze method as computer simulation, physical model analyze and post-occupancy assessment are needed to be investigated and developing a methodology is a necessity to meet the ultimate target. This paper is mainly focused on showing the method proposal for a daylighting design. As part of this research, an experiment is proposed over built-up solar houses, and metrics are needed to be defined. The proposed methodology is split up into three phases, these are daylighting metrics, performance measurement, and impact over research and education. Proposed phases and targets are depicted in Table 2. Targets show up in this table that needs advanced study and shall be discussed separately as future research.

Table 2: The proposed method for research development.

Phase 1		Phase 2	Phase 3
The daylight metrics		**The daylight performance**	**Impact on research and education**
a	Qualitative and quantitative metrics to measure daylight performance	Daylight performance of the built-up solar house	Guidance over design for new solar houses
b	Daylight metrics for post-occupancy assessment	Validation of emerging metrics	Adoption of results into education

3.1 The daylight metrics

Emerging metrics besides current metrics, make more complicated measurements of the daylighting performance of a building which needs expertise in different fields such as computer simulation, photography, solar path, etc. As a research field, the integration of these diverse performance measurement tools needs further study which means open to new researchers. The daylight metrics can be categorized into two as schematic or early design phase and the design development phase which is derived from the traditional project development process (Table 3). Current metrics are mostly used in the schematic design phase and emerging metrics are used in the latter one.

Table 3: Daylighting metrics during schematic/early design and design development phases

Schematic Design		Design Development
1	Solar paths analyze	Computer simulation
2	Massing studies & daylighting metrics	HDR imaging technique
3	Sunlight shading calculation	Heliodon analysis with a physical model

Daylight calculations have been started at the Northern European countries. Sky conditions in these countries are mostly cloudy sky. Therefore, overcast sky model is widely used in daylight calculations. However, as you get closer to the equator line, the use of overcast sky model will not provide a reliable data for these regions. The glare level in Zenith will increase as a result. However, in this study, overcast sky model is accepted in order to meet minimum requirements. Sky conditions in daylighting calculation is another topic to be investigated and discussed which is out of topic of this research.

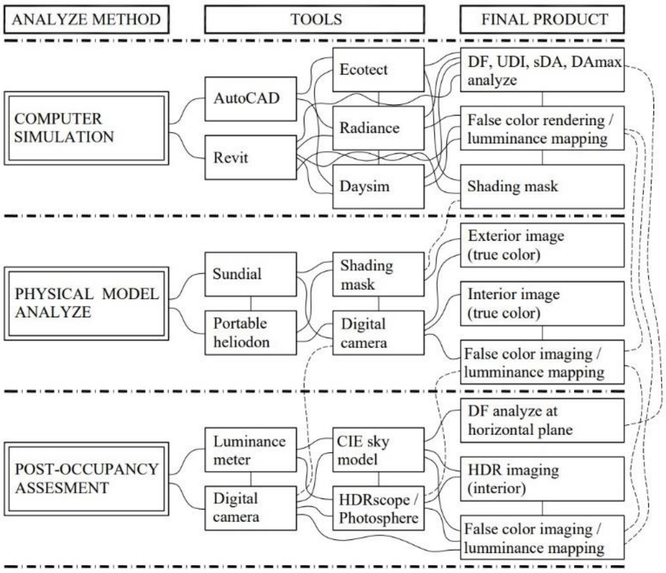
The oldest daylight availability metric is daylight factor, defined as the ratio between the illuminance at a sensor point inside the space to the illuminance at an unshaded, upward facing exterior reference point, under CIE standard overcast sky conditions. The most common computer-based evaluation of daylight availability to date begins by defining a grid of upward facing sensors offset from the floor (usually at desk height) followed by an evaluation of the daylight at these sensors using various criteria/metrics [3]. The annual amount of daylight in a space can nowadays be quantified via so called dynamic or climate-based metrics. As the name suggests, these metrics are derived from annual illuminance profiles, i.e., hourly or even sub-hourly time series of interior illuminance or luminance due to daylight that are generated using a local climate file [14]. Current and emerging daylight availability metrics are daylighting factor (DF), useful daylight illuminance (UDI), spatial daylight autonomy (sDA), annual sunlight exposure (ASE) and these metrics are used to meet criteria of LEED v4 and lighting measurement protocol by Illuminating Engineering Society of North America (IESNA) [15]. Daylight autonomy (DA) is a climate-based metric defined as the percentage of occupied times in the year during which minimum, program-specific illuminance levels can be met by daylight alone. The IESNA committee currently favors a target illuminance 300lux for offices, classrooms and library type spaces, occupied hours from 8 am to 6 pm local clock time. According to the IESNA lighting measurement, a point is considered to be “daylit” if the daylight autonomy exceeds 50% of the occupied times of the year [3]. Another climate-based metric called useful daylight illuminance (UDI) was introduced by Mardaljevic and Nabil in 2006 [16]. UDI largely resembles DA but defines lower and upper illuminance thresholds of 100lux and 2000lux for daylight to be “useful”. Due to the two levels, each point in a space has three UDI values: the percentage of the occupied time when the illuminance at the point is below 100lux, above 2000lux or in between [3]. In order to run these daylight analyzes, computer simulation, hdr imaging technique and physical model with heliodon are the tools to provide final product.

A daylighting study can be organized into three categories analysis method, tools, and final product. Since, considering the built-up solar house as a case study, analysis methods are addressed as computer simulation, a physical scaled model with heliodon, and post-occupancy assessment. Post-occupancy assessment needs illuminance measurement at desk level in a defined time-period. Proposed analysis tools and interaction with each other are graphically illustrated in Table 4.

Due to the complexity of the interaction of these metrics, daylighting analysis has not been widespread in practicing communities, and it is mostly considered a subject among researchers. It is obvious that this interaction shall be verified by performing a case study on the built-up solar house. Strengths and weaknesses of this interaction workflow in

Table 4 need to be discussed based on further research findings.

Table 4: Proposed interaction of emerging analyze tools and final products for advanced daylighting study over solar house.



3.2 *The daylight performance*

The U.S. Department of Energy Solar Decathlon is an international collegiate competition made up of 10 contests that challenge student teams to design and build full-size, solar-powered houses. The competition committee expects teams to blend design excellence and smart energy production with innovation, market potential, and energy and water efficiency. The first Solar Decathlon was held in 2002 and the competition has since occurred biennially [14]. Daylighting performance of a solar house also affects its excellence of visual comfort, well-being, and energy efficiency. Missouri University of Science & Technology has participated solar decathlon several times and the buildings were relocated to their permanent lots on the campus called solar and eco-village consecutive years after the contest. The region is coordinated at N37 and W91 in terms of latitude and longitude. The topographical terrain can be accepted flat even though there is slight slope existence which can be negligible. Solar arrays at roof are faced through south direction in general. Three of them were selected as a case study for daylighting performance measures. Design initiatives are different from each other and each has a unique concept in 2009, 2013, and 2015 (Figure 2).

Figure 2: Solar decathlon entries of Missouri University of Science & Technology; 2009 (left), 2013 (center), 2015 (right) [17]

Building orientation, fenestration system, shading design, and interior spaces follow up concepts and result in a different visual effect on the human eye in terms of daylighting performance. These homes are living labs for prospective research on sustainability and daylighting. Hence, the measurement of daylighting performance of these built-up solar houses can provide valuable data as research findings and results can be compared with each other. Moreover, the comparison may provide deviation/accuracy of applied daylighting metrics based on a proposed case study.

Table 5: Proposed tasks and outputs

Tasks		Computer Simulation	Physical Model Analyze	Post-Occupancy Assessment
1	Investigate DF or DA level	X		X
2	Develop luminance mapping	X		X
3	Explore shading mask	X	X	
4	Construct scaled model		X	
5	Validate heliodon and sundial setup		X	
6	Validate HDR imaging			X

Based on proposed interaction of emerging analyze tools in Table 4, detailed performance tasks and outputs are shown in Table 5. Outputs are scheduled in different levels as computer simulation, physical model, and post-occupancy. Impact on research and education can be measured by using the data provided by this research.

3.3 Impact on research and education

a. Daylighting guideline for design parameters with recent technology for new solar houses

Emerging metrics on daylighting technology in recent years have provided some new tools to the building designer. The problem is how to make use of these technologies in the overall daylight integration. The proposed model is to develop an educational toolkit on different building programs for residential use. Missouri University of Science & Technology is in a unique position as it has participated numerous times in the Solar Decathlon which is held biannually by the U.S. Department of Energy since 2002. As a result, the university has a unique solar/eco-village that provides an ideal case study to develop a series of educational methods ultimately leading to a daylighting toolkit for building designers.

Prospective research findings of a daylighting analysis on solar houses will have a positive impact on solar house design development. Emerging metrics, the workflow of interaction, and analysis tools will be evaluated and verified by future research. Building orientation, and window direction such as south and north windows, overhang, and shading devices will be compared. Furthermore, provided data can be used for integration with smart living features. Since, daylighting is more popular among researchers, rather than practicing communities, research findings will contribute to the research community. On the other hand, results will be a guideline/roadmap for designers who engage with solar house design for the upcoming U.S. Solar Decathlon.

b. Curriculum development

The results of case studies will also help daylight technology education by improving course curriculum, material, and assignment contents. Students will actively involve in daylighting design by preparing a term project which follows the workflow of analyzing tools used in proposed case studies. Based-on motivations on research background, a daylighting course part of sustainable design and smart living would provide valuable perspective to architectural engineering education. Since the entries to Solar Decathlon are performed through student participation, the curriculum development will provide positive impact on experiential learning.

4. Conclusion

The popularity of sustainable and energy efficient building design result-in development of diverse sub-trade expertise such as daylighting. Being still new research field, variety of luminance measurement methods are developed, and some are classified as emerging metrics. These metrics are popular in research community but needs to be widespread in the practicing community as well. The challenge definition shows how to design solutions, analyze tools effectively interact with each other. To aid solar house design in terms of daylighting context an experiential method is proposed. The paper presents the proposed phases of daylighting study which will be a roadmap for preparing a design guide for new solar houses. The research method proposed herein can be used in the future on new solar houses beside the existing ones in the world. Computer simulation, physical model, and post-occupancy are used during design development as emerging metrics, and validation of these metrics is proposed to be tested in selected built-up solar houses in Missouri University of Science & Technology campus. First, performance measurements of built-up solar houses are necessary to validate emerging metrics, and it is recommended to use this proposed methodology to apply over different built-up solar houses in the world. Secondly, it is recommended that a design guide can be generated based-on these findings, which will be used during design development of new-solar house design. The results of the research findings will be helpful to researchers and educators who deal with sustainability and energy efficiency. It would be beneficial in the future to have this as a design guide, especially for residential buildings rather than just solar houses. Furthermore, developing a daylighting guideline and curriculum development are concrete targets of this proposed method. Different phases of this proposed method need to be investigated and discussed separately. Qualitative and quantitative metrics to measure daylight performance (Table 2; Phase 1a) are determined and results are adopted into education (Table 2; Phase 3b) by developing an experiential course named "daylighting" in Architectural Engineering Program. Another paper will be particularly dedicated to the educational adaptation of daylighting design.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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Influence of the Web Opening Shapes on the Bending and Free Vibration Responses of Castellated Steel Beams

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Abstract - In recent years, the use of castellated beams has increased significantly across all types of structures. The castellated beam is one of several methods for reducing the weight and cost of steel in construction. In this study, the static and dynamic behavior of castellated beams is investigated via the three-dimensional finite element method. The primary objective of this study is to investigate in detail the effect of web opening shapes on displacement, stress values, and free vibration of castellated beams. The investigation is done using ANSYS 22 R1. In the analysis, 4 different web opening types circle, square, pentagon, and hexagon are used. To generate the models via the finite element method a 10-node tetrahedral type finite element is implemented. This study will employ a linear isotropic homogeneous material with the mechanical properties of steel. As boundary conditions, fixed – fixed, fixed – pinned, and fixed – free are considered. The results for circular, square, pentagon, and hexagon castellated beams made from IPE120, IPE180 and IPE240 profiles are presented in detail. Based on the results, it is seen that the type of web opening has a significant effect on the displacements, von-Mises stresses, maximum shear stress and free vibration values of the considered structures.

Keywords: Castellated Beam, Total Displacement, Finite Element Method, Free Vibration, Maximum Shear Stress, Von Mises Stress

1. Introduction

The usage of castellated beams has become very popular due to their advantageous structural applications such as they are light, cheap, have relatively high resistance, and can be assembled fast at the construction site. These applications make use of the increased strength and cost of castellated beams[1]. In the 1930s, castellated shapes were manufactured by the Skoda factories in Pilsner and were first traded in the United Kingdom [2].In the mid-1930s, an engineer working in Argentina, Geoffrey Murray Boyd, castellated beam, which was one such improvement in built-up structural members [3].

Studies on web opening configurations involving square, rectangular, circular, concentric, and eccentric openings of steel beams were completed in the early 1960s in the United States and Canada [2] . A castellated beam is made from a standard I-beam through the use of a cutting and welding process. Since the 1980s, researchers have studied castellated beams using both experimental and finite element numerical methods [4]. Various methods have been used to study the response of castellated beams [5].

The theoretical basis of the castellated beam is an attempt to increase the profile height of the beam while creating openings in the web of the profile, thereby increasing its moment of inertia while decreasing its self-weight. The failure mode of the structure is affected by modifications made to the castellated beam. The formation of a Vierendeel mechanism, lateral torsional buckling of the web post, rupture of a welded joint in a web post, lateral torsional buckling of the entire span, formation of a flexure mechanism, and buckling of the web post were all possible modes of failure [6]. The openings are typically hexagonal, square, or circular in shape. The beams with holes in the shape of a circle are called cellular beams[7]. The main reasons for fabricating castellated beams are (a) increasing section height, which enhances moment of inertia, section modulus, stiffness, and flexural resistance; (b) decreasing profile weight, which reduces structure weight and saves construction work; (c) optimum utilization of existing profiles; (d) no need to plate girders; and (e) the passage of services[8]. Vibration analysis is critical for the design of structures subjected to dynamic loadings [9]. The free vibration analysis of I-section beams is well understood and covered in many textbooks. However, difficulties arise for castellated beams due to web openings, which cause not only section property variation along the longitudinal axis of the beams but also shear weakness of the web. The latter necessitates an analysis that accounts for the shear effect[10]. Mathur et al. [11] performed the static and dynamic analyses of the castellated steel beam section (ISMB 300) to compare deflection, stress distribution, shear stress, amplitude, and natural frequency. ANSYS 18 is used to investigate. El-Dehemy[12] the ABAQUS software to analyze the nonlinear static and dynamic steel beam openings with different positions and supporting conditions.

Lotfollahi andAhmadi [13] used ANSYS to study castellated beam dynamics. First, the dynamic properties and mode shapes of plain-webbed and castellated cantilever beams were studied. Large web openings may reduce castellated beams' dynamic load-carrying capacities. Plainwebbed and castellated beams were then subjected to a white-noise dynamic load. Dynamic cantilever castellated beam properties depend on the loading pattern. Akgönen et al. [14] A 3D Finite Element Analysis (FEA) was performed to determine the flexural and elastic lateral-torsional buckling behavior of a cellular beam using the shape and quality of European steel. The finite element model was verified using a literature-based experiment (FEM). Doori and Noori [15] the static behavior of castellated beams with varying web apertures ABAQUS is used to do a 3D finite element analysis to determine which type of beam provides the highest performance under the same distributed load and fixed support condition. Abdulkhudhur et al. [16] evaluate the shear buckling capacity of floor steel beams with circular web perforations under static and dynamic loads. Web-to-thickness ratio and perforation size were used. ANSYS software was used to simulate all models as three-dimensional problems. Salah [17] used a developed Finite Element (FE) model, the current study predicts the up to failure behavior of hybrid castellated beams (HCBs). In their study, 410 MPa steel was used for flanges and 250 MPa for web. ANSYS was used for the analysis. Morkhade et al [18] used the finite element model including geometric and material nonlinearity. Failure modes, load–deflection behavior of samples, and stress concentration with opening size, shape, and position were studied. Hosseinpour and Sharifi [19] studied the web distortion's effect on steel beam buckling. To this purpose, a series of nonlinear finite element (FE) models were constructed and well verified against an experimental work on the distortional buckling of castellated beams; both material nonlinearities and initial geometric imperfections were carefully applied to the models. Vivek et al. [20] analyzed the free and harmonic vibration of steel thin-walled tapered cantilever beams with and without web openings.

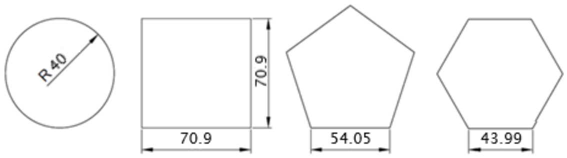
Frans et al. [21] studied the hexagonal castellated beams studied numerically for opening angle and spacing. ABAQUS/CAF v6.11 was used to develop a finite element model based on the Von misses failure principle. Soltani et al. [22] employed the MSC/NASTRAN model to predict the developed the behavior of castellated beams with octagonal and hexagonal holes, both material and geometric nonlinearities were considered in the numerical model. Shaikh and Autade[23] studied in this the experiment in the castellated beam was investigated of buckling capacity of the web post with a fillet corner, hexagonal web opening was compared to the circular opening as Concentrated load or reaction point over a web-post . Finite element analysis was done by using ANYSIS 14. The results pointed out that using of a vertical stiffener reduces the deflections about 20% compared to these without stiffeners, while using of a diagonal and vertical stiffener with each other reduces deflection about 60 % compared to the castellated beam without stiffeners. Wang et al. [24] adopted the finite-element method in study of elastic buckling behavior in castellated beams at the web-post which subjected to vertical shear. Zaarour[25] tested twelve of the castellated beams until reach to fail with respecting the buckling of web-post between holes. In the same direction, the buckling loads were calculated using a finite element method in addition to the experimental method. Redwood and Demirdjian [26] tested four castellated beams.Web post-buckling was the focus of the study which was observed in all beams of the test. Buckling loads were predicted by elastic analysis by using the finite element method. The test results showed that the buckling load non-sensitive to the ratio of (moment/shear). Estrada et al. [27] compared the costs of a castellated beam and standard wide flange beams. The results explained that the castellated beams were more advantageous compering with unaltered standard wide flange beams at the same load capacities.

The literature survey shows that the influence of the web opening shapes on the static and dynamic analysis of castellated steel beams has been not investigated by using the 3D finite element method (FEM) via ANSYS 2022 R1 yet. This paper aims to examine the static and dynamic response of castellated beams with the aid of the finite element method. The effects of different boundary conditions and the web opening geometries (square, circle, pentagon, and hexagon) of the castellated beams on the displacements, stresses, and free vibration characteristics are parametrically investigated.

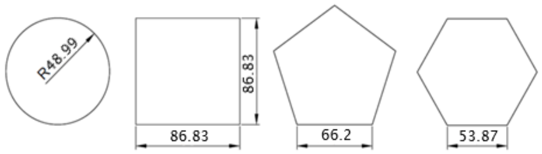
To present this research paper in a better way, it is organized as follows: Section 2 shows the materials and gives information about the finite element type used in the analysis. Section 3 presents the numerical results and discussion. and Section 4 gives the most important conclusion of this paper.

2. Materials and Method

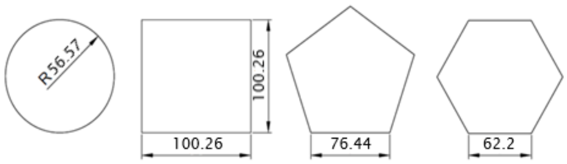
This study analyzes castellated beams with different geometries using the ANSYS Workbench 2022 R1 based on the finite element method. IPE120, IPE180, and IPE240 profiles are used in the analyses; each profile contains four different web opening types (circle, square, pentagon, and hexagon).The geometric properties of the web opening of these beams are shown in Figure 1. and the material properties are presented in Table 1.



(a) IPE120



(b) IPE180



(C) IPE240

Fig. 1: web opening geometric

Table 1. Material properties

Young's Modulus Pa	Poisson's Ratio	Bulk Modulus Pa	Shear Modulus Pa
2.E+011	0.3	1.6667E+011	7.6923E+010

The length of the castellated beam is taken as 3 meters. In all types, the opening number is 15, the distance between the centers of the opening (α) is 0.18 m, and the length (β) between the support and the center of the opening is 0.24 m. These features are summarized in Table 2.

Table 2. Geometric properties of web opening

Model	Profil type	Web opening type	Area opening (mm^2)	α (m)	β (m)
I	IPE120	circular	5026.55	0.18	0.24
II	IPE120	Square	5026.55	0.18	0.24
III	IPE120	pentagon	5026.55	0.18	0.24
IV	IPE120	hexagon	5026.55	0.18	0.24
V	IPE180	circular	7539.89	0.18	0.24
VI	IPE180	Square	7539.89	0.18	0.24
VII	IPE180	Pentagon	7539.89	0.18	0.24
VIII	IPE180	Hexagon	7539.89	0.18	0.24
IX	IPE240	circular	10053.61	0.18	0.24
X	IPE240	Square	10053.61	0.18	0.24
XI	IPE240	pentagon	10053.61	0.18	0.24
XII	IPE240	hexagon	10053.61	0.18	0.24

In the finite element solution of the problem in the hand with ANSYS, the three dimensional SOLID187 is used.The element is defined by 10 nodes while each node has three degrees of freedom. The SOLID187 has a quadratic shifting behavior and is suitable for modeling of the finite element irregular mesh. The degrees of freedom in the elements consist of translations in the direction of the x, y, and z axes. More detailed information about the theory of this element and the geometry of this element can be found in [28]

In this research, no changes were made to the "Mesh" settings of the program while creating the finite element mesh of the systems. The number of elements and nodes for each case is presented in Table 3.

Table3. Finite element mesh properties

Model	Number of element	Node number
I	5128	11002
II	4505	9468
III	3257	6595
IV	5209	11157
V	5289	11660
VI	4146	8820
VII	4455	9605
VIII	4856	10614
IX	5458	12442
X	3676	8160
XI	3951	8894
XII	4301	9875

Three different boundary conditions have been taken into account fixed – fixed, fixed–pinned, and fixed–free shown in Table 4, 'i' denotes the left end of the beam, while 'j' stands for the right end of the beam. In order to define the support boundary conditions, the "Fixed" condition in the interface of the program for the fixed support is used. for the pinned support using the "Remote Displacement" command. No boundary conditions were entered for the free end.

Table 4: Boundary conditions

Type of the support	Boundary conditions	
	i	j
Fixed – Fixed (F-F)	Fixed Condition	Fixed Condition
Fixed – Pinned (F-P)	Fixed Condition	Remote Displacement
Fixed – Free (F-FR)	Fixed Condition	-----

2.1 Static Analysis

After modelling the analysis is carried out in ANSYS2022 software and results are obtained for deformation, equivalent (von-mises) stress and maximum shear stress. Graphs are prepared from the results and comparison is done.

2.2 Dynamic Analysis

After modeling, analysis results are obtained for the natural frequency and mode shapes are obtained.

3. Numerical results and discussion

In this study, the static and dynamic analysis of castellated beams are carried out with the help of three-dimensional finite elements. The ANSYS [29] Workbench package is used in the analysis. The effect of the web opening shapes on the performance of the structural elements is investigated in detail. The pressure is applied to the top of the beam, and its value was taken as 1000 Pa. It is worth mentioning that there is no specific reason for choosing this load. It is considered only to investigate the effect of web opening type on the static response of the castellated beams. Three types of profiles used in this study are IPE120, IPE180, and IPE300 profiles for castellated beams. For each one of these profiles, 4 different web opening types (circle, square, pentagon, and hexagon) are used. In this context, only the web opening type is changed by keeping the length of the beam, the web opening area, and the distance between the openings equal in the cases for each profile. The material properties are assumed as in Table 1.

3.1 Static Analysis

Thirty six different models are generated and analyzed using the finite element procedure. To outline the effect of web opening on the static response of the considered structure, results are obtained for values of web opening type and boundary conditions**.**

The total displacement values obtained for all models will be discussed first in this section.The results obtained are shown in Figure 3 for the fixed-fixed boundary condition and are given in Table 5 for the other boundary conditions.

When Figure 11 and Table 5 are examined in all support conditions, the largest total displacements in the castellated beam occur in the case of a square web opening, and the smallest total displacements occur when a pentagon web opening is used in profile IPE120, while the smallest displacements occur when a hexagon web opening is used in other profiles. The total displacement values of castellated beams with circular web openings are approximated when hexagonal web opening geometry is used. Profil type and deflection curves for all support conditions of castellated beams are presented in Figures (2–10).

Table 5. Maximum total displacement values for castellated beam (m).

Support Condition	Profil	Model	Maximum dispacement (m)
Fixed - Fixed	IPE120	I	2.499E-05
		II	2.554E-05
		III	2.425E-05
		IV	2.508E-05
	IPE180	V	1.030E-05
		VI	1.098E-05
		VII	1.044E-05
		VIII	1.028E-05
	IPE240	IX	5.989E-06
		X	6.736E-06
		XI	6.089E-06
		XII	5.958E-06
Fixed- Pinned	IPE120	I	4.893E-05
		II	4.960E-05
		III	4.820E-05
		IV	4.905E-05
	IPE180	V	1.873E-05
		VI	1.955E-05
		VII	1.890E-05
		VIII	1.872E-05
	IPE240	IX	9.935E-06
		X	1.085E-05
		XI	1.008E-05
		XII	9.926E-06
Fixed - Free	IPE120	I	1.046E-03
		II	1.048E-03
		III	1.043E-03
		IV	1.047E-03
	IPE180	V	3.621E-04
		VI	3.656E-04
		VII	3.649E-04
		VIII	3.638E-04
	IPE240	IX	1.667E-04
		X	1.701E-04
		XI	1.672E-04
		XII	1.664E-04

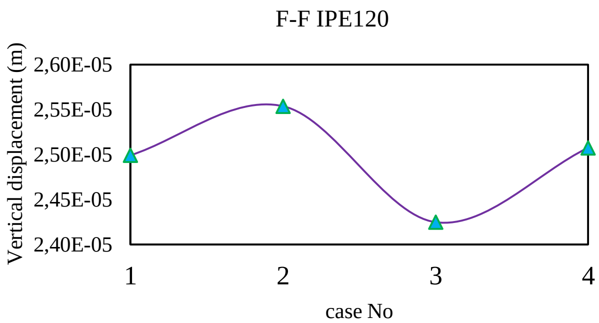


Fig. 2: Profil type – deflection curve for fixed –fixed castellated beam

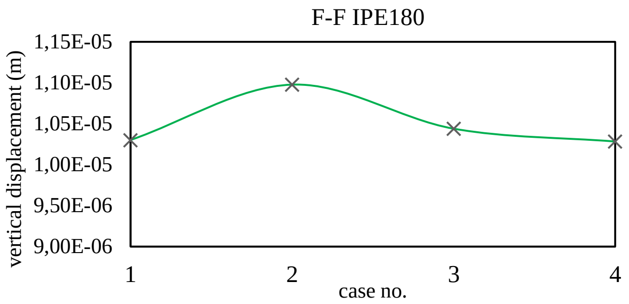


Fig. 3: Profil type – deflection curve for fixed –fixed castellated beam

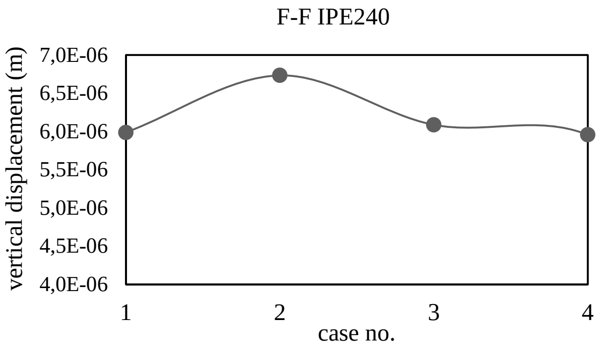


Fig. 4: Profil type – deflection curve for fixed –fixed castellated beam

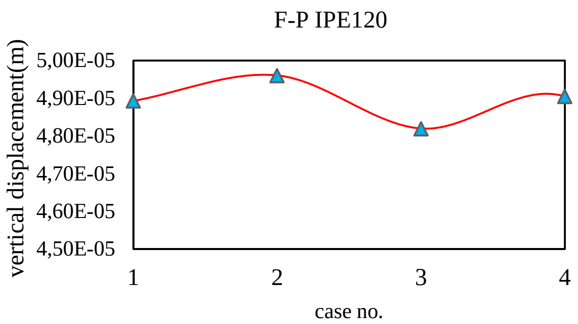


Fig. 5: Profil type – deflection curve for fixed –pinned castellated beam

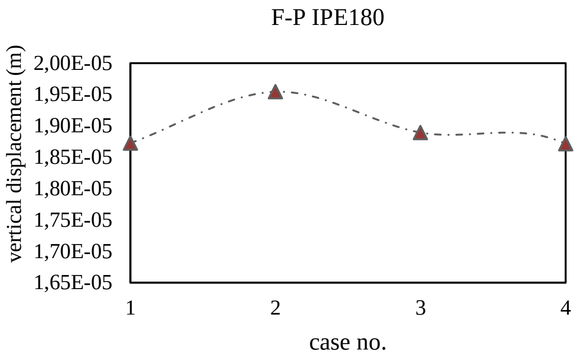


Fig. 6: Profil type – deflection curve for fixed –pinned castellated beam

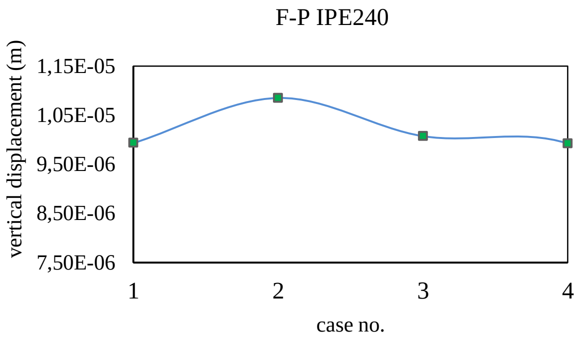


Fig. 7: Profil type – deflection curve for fixed –pinned castellated beam

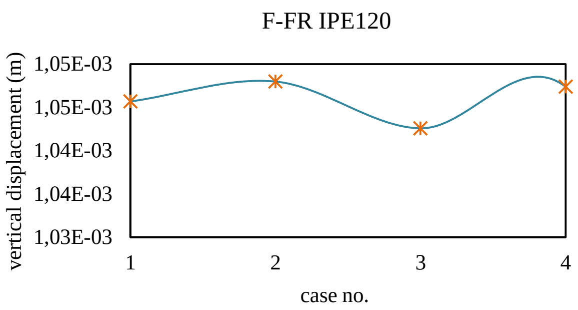


Fig. 8: Profil type – deflection curve for fixed –free castellated beam

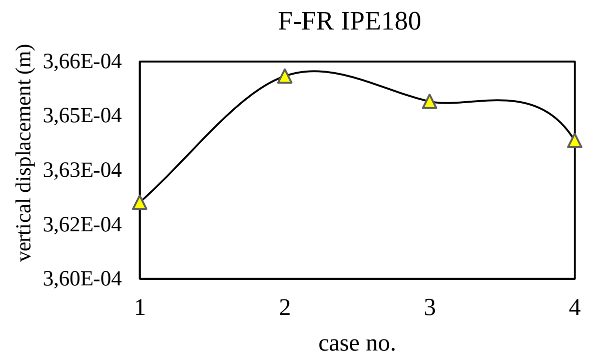


Fig. 9: Profil type – deflection curve for fixed –free castellated beam

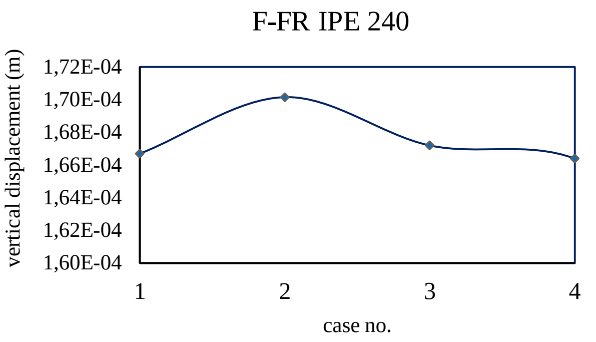


Fig. 10: Profil type – deflection curve for fixed –free castellated beam

Table 6: Maximum von Mises stress values for castellated beam (pa)

Support Condition	Profil	Model	Maximum von mises stress (pa)
Fixed - Fixed	IPE120	I	1.107E+06
		II	1.428E+06
		III	1.081E+06
		IV	1.661E+06
	IPE180	V	8.556E+05
		VI	1.040E+06
		VII	1.286E+06
		VIII	1.105E+06
	IPE240	IX	8.531E+05
		X	8.748E+05
		XI	7.840E+05
		XII	7.272E+05
Fixed- Pinned	IPE120	I	1.403E+06
		II	1.914E+06
		III	1.378E+06
		IV	2.173E+06
	IPE180	V	1.061E+06
		VI	1.229E+06
		VII	1.242E+06
		VIII	1.443E+06
	IPE240	IX	1.076E+06
		X	1.132E+06
		XI	1.003E+06
		XII	9.242E+05
Fixed - Free	IPE120	I	5.759E+06
		II	5.689E+06
		III	5.711E+06
		IV	6.874E+06
	IPE180	V	2.912E+06
		VI	2.932E+06
		VII	2.861E+06
		VIII	3.702E+06
	IPE240	IX	1.998E+06
		X	2.212E+06
		XI	2.037E+06
		XII	1.930E+06

The von Mises stress values are obtained as a result of the static analysis for all models considered within the scope of the study and are given in Figure 12 for the fixed-pinned boundary condition. The minimum and maximum von Mises stress values calculated for all other boundary conditions are given in Table 6. submitted for review.

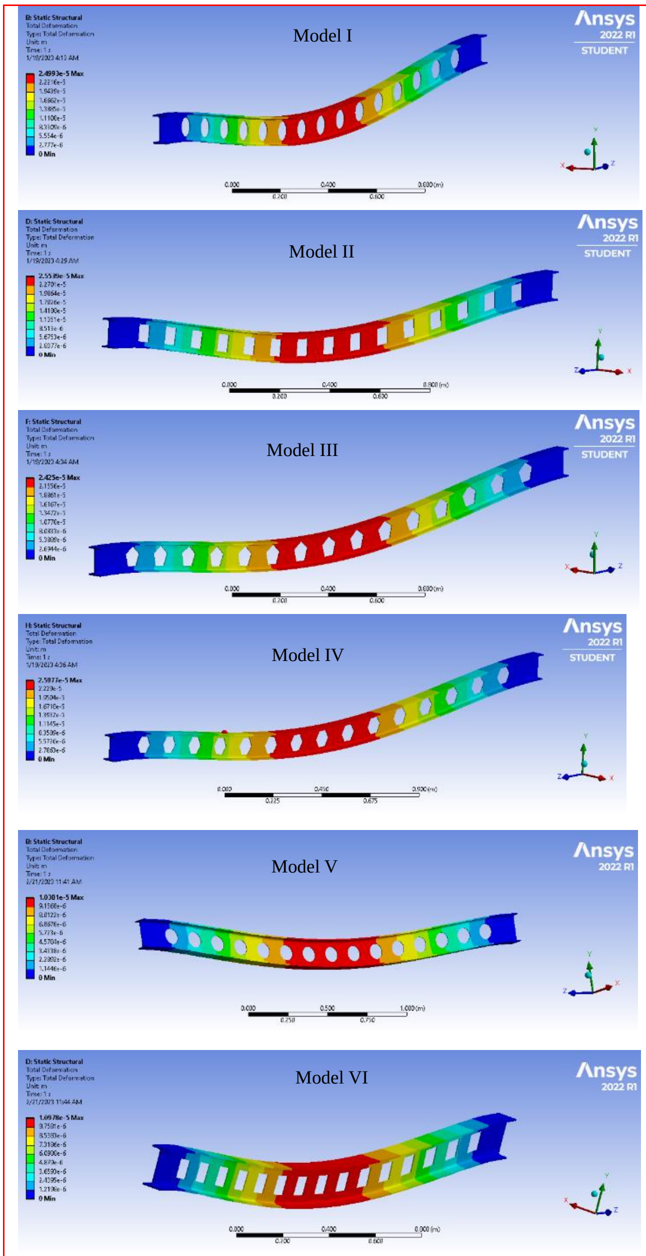
As seen in Figure 12 and Table 6, the lowest von Mises stress values for the IPE120 profile occur when a pentagon web opening is used. For the IPE180 profile, these values are the lowest when circular web opening is used in fixed-fixed and fixed-pinned, while these values are the lowest when pentagon web opening is used in fixed-free. The lowest von Mises stress values for the IPE240 profile occur when a hexagonal web opening is used. When the hexagonal web opening type is used for both profiles IPE120 and IPE180, von-Mises stresses take the highest values. While profile IPE 240 has a square web opening type, von-Mises stresses are the highest. .

In order to better determine the effect of the web opening geometry on the static behavior of the castellated beams, the maximum shear stress values are also obtained. These values are given in Figure 13 for the cantilever beam. These values are presented in Table 7 for all other support conditions. When Table 7 and Figure 13 are examined, the maximum shear stress values for the IPE120 and IPE180 profiles in fixed-fixed and fixed-pinned support cases are the lowest when castellated beams with circular openings are used.

Table 7. Maximum shear stress values for castellated beam (pa).

Support Condition	Profil	Model	Maximum shear stress (pa)
Fixed - Fixed	IPE120	I	5.622E+05
		II	7.895E+05
		III	5.903E+05
		IV	8.669E+05
	IPE180	V	4.301E+05
		VI	5.792E+05
		VII	6.845E+05
		VIII	5.861E+05
	IPE240	IX	4.285E+05
		X	4.840E+05
		XI	4.155E+05
		XII	3.837E+05
Fixed- Pinned	IPE120	I	7.044E+05
		II	1.057E+06
		III	7.195E+05
		IV	1.142E+06
	IPE180	V	5.402E+05
		VI	6.824E+05
		VII	6.788E+05
		VIII	7.666E+05

	IPE240	IX	5.435E+05
		X	6.265E+05
		XI	5.414E+05
		XII	4.993E+05
Fixed - Free	IPE120	I	2.806E+06
		II	2.880E+06
		III	2.875E+06
		IV	3.554E+06
	IPE180	V	1.494E+06
		VI	1.499E+06
		VII	1.520E+06
		VIII	1.963E+06
	IPE240	IX	1.013E+06
		X	1.234E+06
		XI	1.112E+06
		XII	1.019E+06



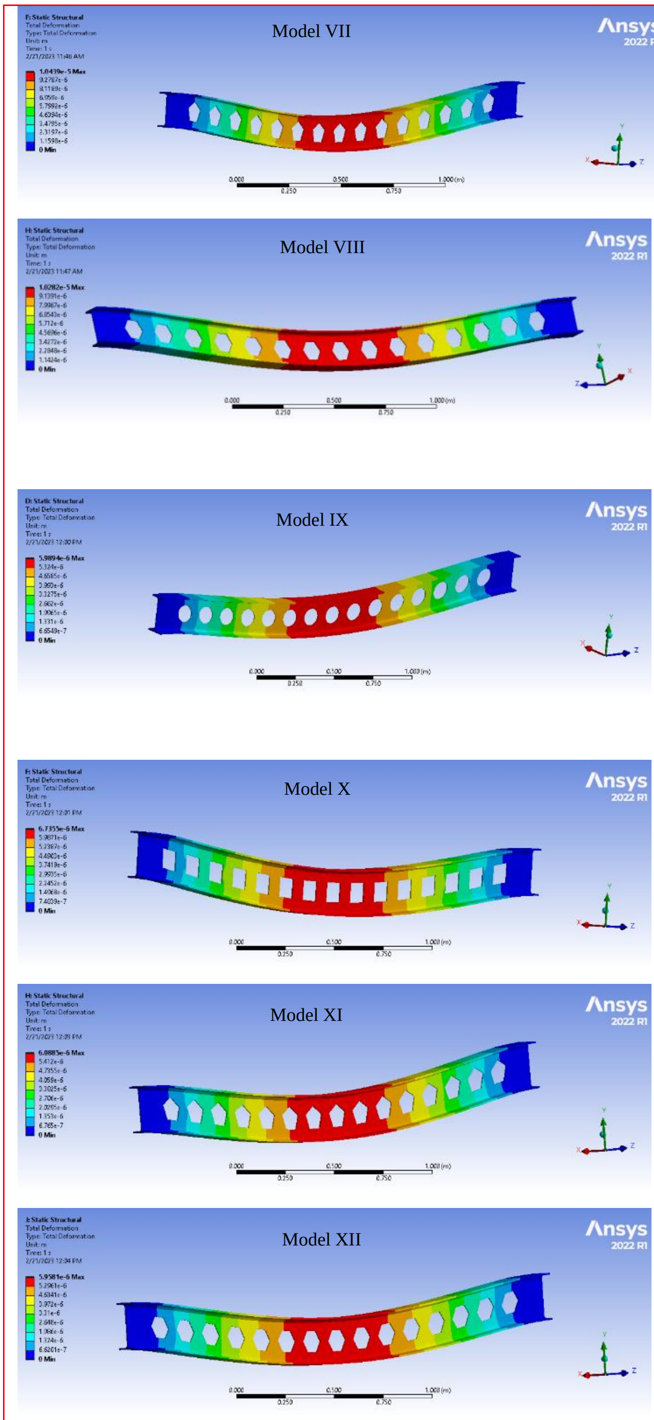
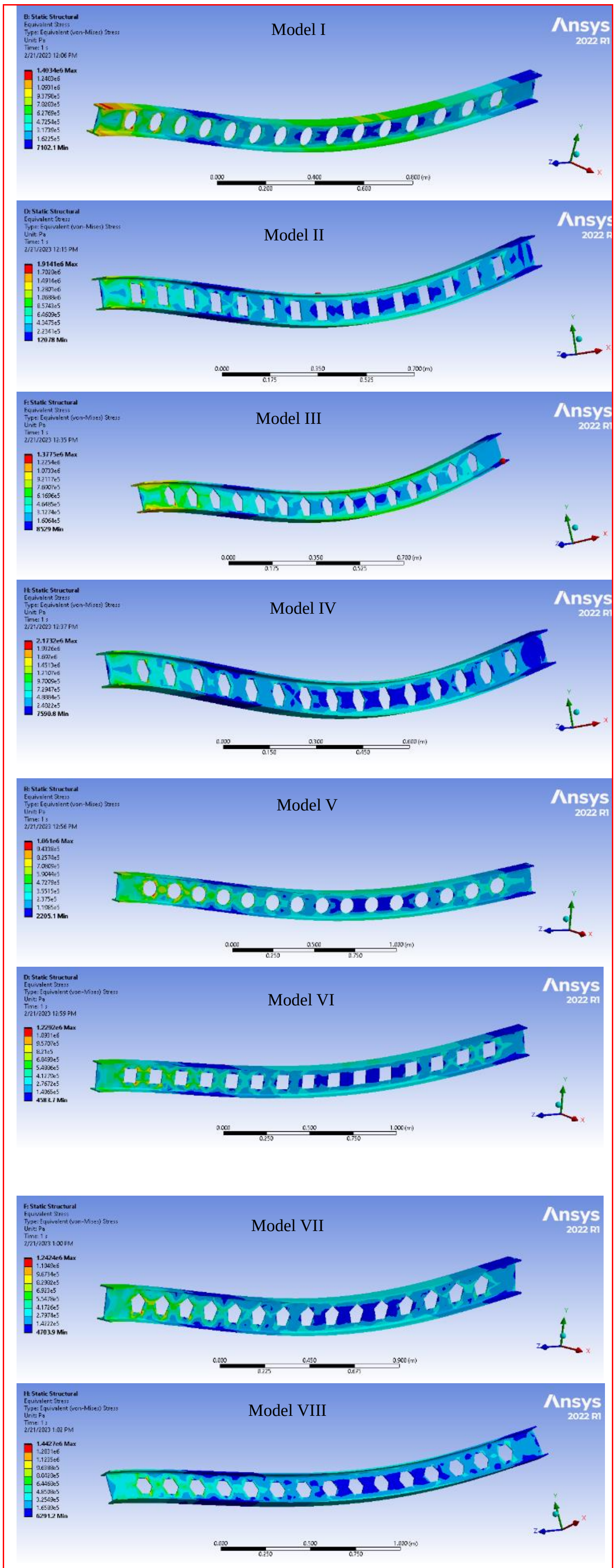


Fig. 11: The total deformation for fixed – fixed castellated beam

For the IPE 240 profile, the lowest maximum shear stress values occur when a hexagonal-type opening is used. For a cantilever beam, the IPE120, IPE180, and IPE240 profiles with a circular opening have the lowest maximum shear stress. As can be clearly observed in Tables (5-7) the results gained we can arrange the beam from lower to higher von mises stress based on the beam supports comparison: fixed – fixed, fixed – pinned, and lastly fixed – free.



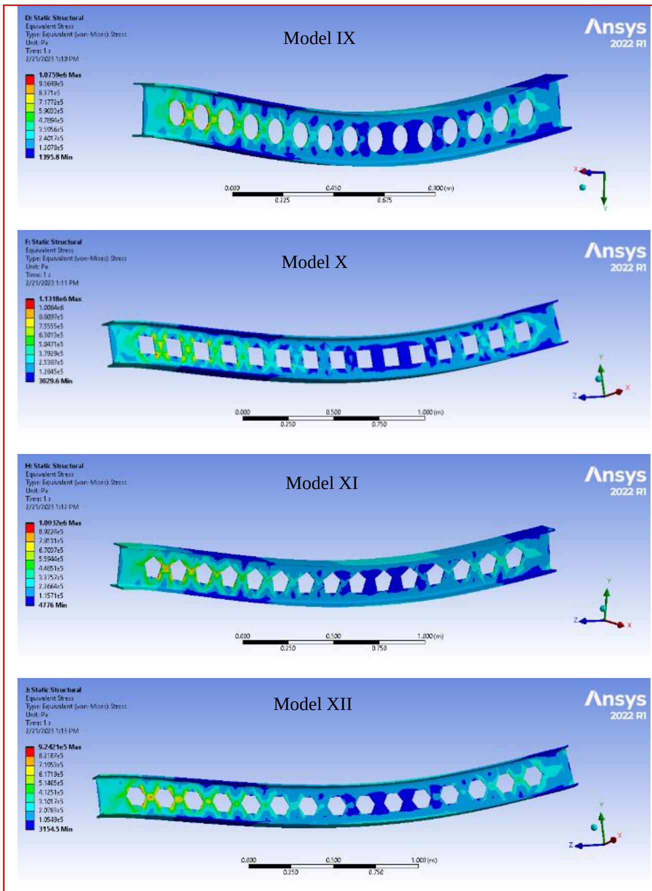
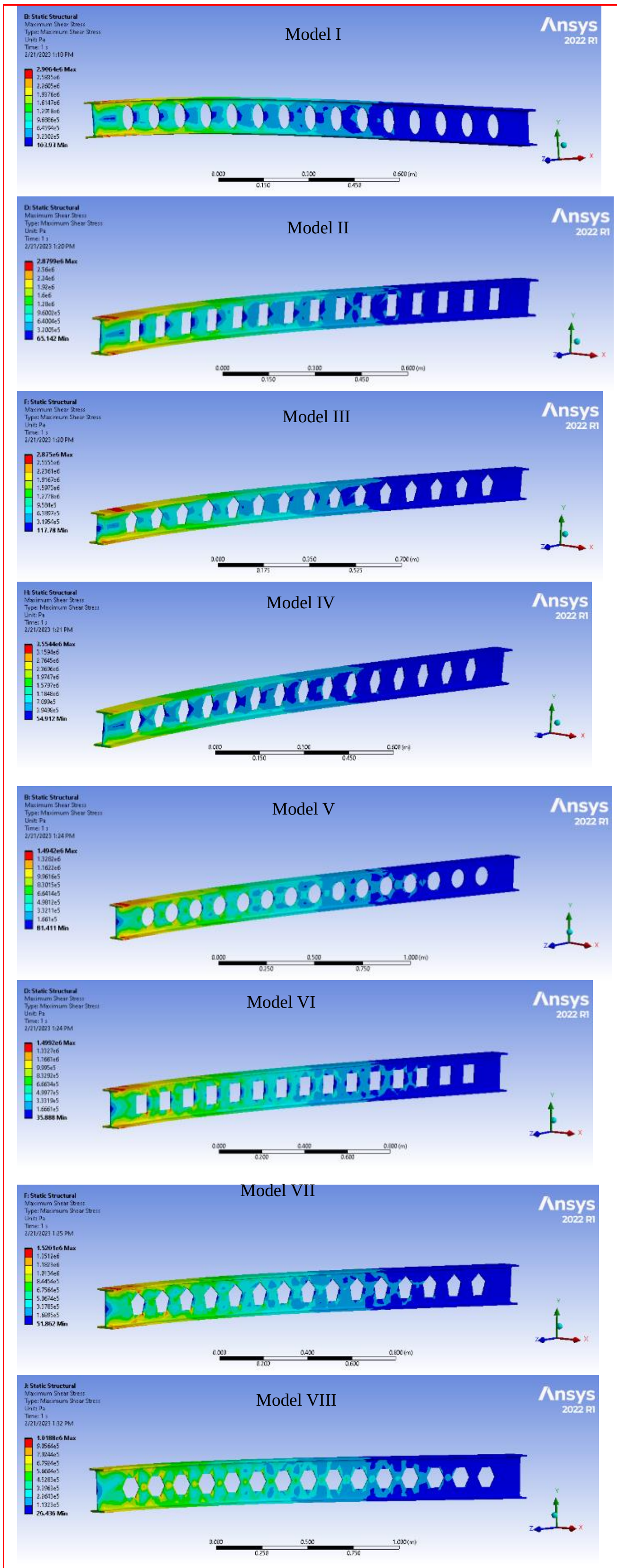


Fig.12: The von Mises stress distributionfor fixed-pinned castellated beam



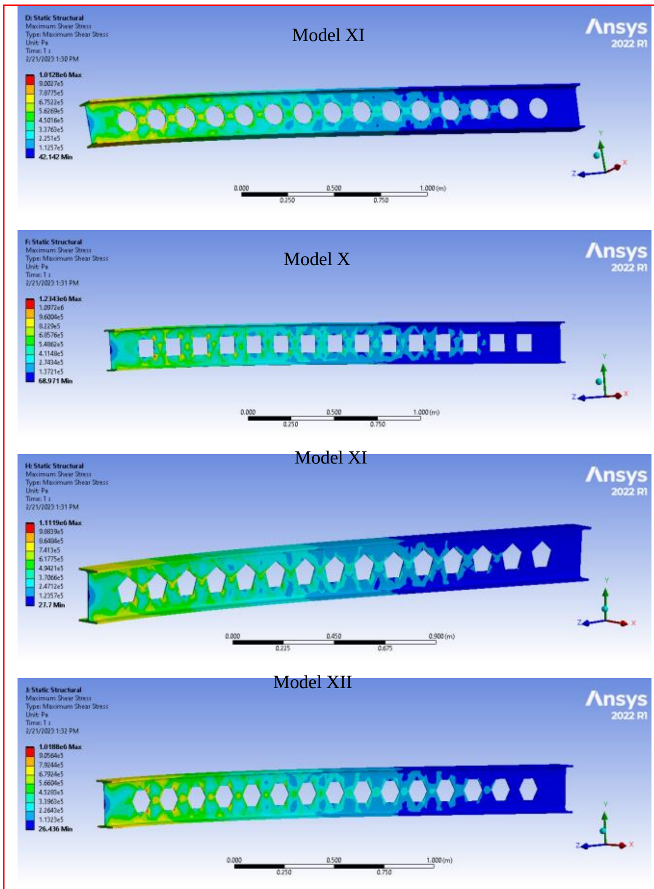


Fig.13: The maximum shear stress for fixed – free castellated beam

3.2 Dynamic analysis

Thirty-six different models are generated and analyzed using the finite element procedure. To outline the effect of web opening on the free vibration response of the considered structure, results are obtained for values of web opening type and boundary conditions.

Table 8. shows some of the essential aspects of the free vibration response of castellated steel beams. From the given comparisons, it is easy to see the influence of the web opening type on the natural frequencies. The five modes have the highest frequency in the pentagon. In the fixed -fixed support the lowest frequency is in the circular in the first, fourth, and fifth modes, and in the hexagonal in the second and third modes. The hexagon has the lowest frequency in the first, second, and fourth modes of fixed-pinned support; the square in the third mode; and the circular in the fifth mode. The lowest frequency in a cantilever beam is in the hexagon in the first, third, and fourth modes; in the square in the second mode; and in the circular in the fifth mod. The comparison of the natural frequency is shown in figures(14-16).

Table 9 shows that the five modes have the lowest frequency in the square. In the fixed -fixed support the highest frequency is in the circular in the first mode and in the pentagon in the second and third modes. The hexagon has the highest frequency in the fourth, and fifth modes. In the fixed-pinned support, the highest frequency is in the circular in the first mode, and the pentagon in the second, third, and fourth modes. The highest frequency in a cantilever beam is in the circular in the first, second, and fourth modes; in the hexagon in the third mode; and in the pentagon in the fifth mode. The comparison of the natural frequency is shown in figures(17-19).

Table 10 demonstrated that for the fixed -fixed support, the highest frequency is in the pentagon in the first mode, in the square in the second, in the hexagon in the third and fourth modes, and in the circular in the fifth mode. The hexagon has the lowest frequency in the first and second modes, and the circular has the lowest frequency in the third and fourth modes; the pentagon has the lowest frequency in the fifth mode.

In the fixed-pinned support, the highest frequency is in the hexagon in the first, second, and fourth modes; in the pentagon in the third; and in the circular in the fifth mod.The circular has the lowest frequency in the first and third modes, and the square has the lowest frequency in the second, fourth, and fifth modes.

In the case of a cantilever beam, the highest frequency is in the square in the first mode, in the hexagon in the second and third modes, and in the pentagon in the fourth and fifth modes. The circular has the lowest frequency in the first and fourth modes, and the square has the lowest frequency in the second, third, and fifth modes. The comparison of the natural frequency is shown in figures(20-22).

The Ansys results indicated that the increase in size of the web opening increased the Frequency.

Table 8. Natural frequencies castellated beam with profil IPE120 (Hz)

Support Condition	Model	Mod	Natural frequency (HZ)
Fixed - Fixed	I	1	30.282
		2	56.783
		3	83.228
		4	94.102
		5	126.99
	II	1	30.295
		2	56.74
		3	83.262
		4	93.029
		5	128.63
	III	1	31.03
		2	85.962
		3	86.334
		4	95.755
		5	170.8
	IV	1	30.265
		2	56.429
		3	83.195
		4	93.892
		5	127.21
Fixed- Pinned	I	1	20.853
		2	24.2
		3	66.932
		4	67.413
		5	76.601
	II	1	20.856
		2	23.982
		3	66.486
		4	67.416
		5	77.981
	III	1	21.291
		2	36.736
		3	67.672
		4	69.381
		5	120.74
	IV	1	20.834
		2	23.646
		3	66.829
		4	67.375
		5	76.824
Fixed - Free	I	1	4.7169
		2	15.727
		3	24.199
		4	29.568
		5	76.597
	II	1	4.7145
		2	15.697
		3	23.981
		4	29.569
		5	77.977
	III	1	4.8126
		2	15.783
		3	30.185
		4	36.738
		5	85.22
	IV	1	4.7137
		2	15.707
		3	23.645
		4	29.544
		5	76.819

Table 9. Natural frequencies castellated beam with profil IPE180 (Hz)

Support Condition	Model	Mod	Natural frequency (HZ)
Fixed - Fixed	V	1	42.738
		2	59.384
		3	116.64
		4	129.3
		5	144.58
	VI	1	42.691
		2	58.977
		3	116.52
		4	125.1
		5	144.23
	VII	1	42.73
		2	59.626
		3	116.71
		4	128.5
		5	144.63
	VIII	1	42.713
		2	59.172
		3	116.59
		4	129.33
		5	144.83
Fixed- Pinned	V	1	21.587
		2	29.453
		3	73.825
		4	94.613
		5	95.469
	VI	1	21.255
		2	29.422
		3	73.115
		4	93.42
		5	94.506
	VII	1	21.445
		2	29.454
		3	74.571
		4	94.643
		5	95.02
	VIII	1	21.414
		2	29.438
		3	73.809
		4	94.579
		5	95.481
Fixed - Free	V	1	6.6758
		2	21.587
		3	23.534
		4	41.75
		5	73.825
	VI	1	6.6697
		2	21.255
		3	23.445
		4	41.71
		5	73.115
	VII	1	6.6694
		2	21.445
		3	23.478
		4	41.738
		5	74.571
	VIII	1	6.6727
		2	21.414
		3	23.547
		4	41.73
		5	73.809

Table 10. Natural frequencies castellated beam with profil IPE240 (Hz)

Support Condition	Model	Mod	Natural frequency (HZ)
Fixed - Fixed	IX	1	55.45
		2	68.795
		3	149.05
		4	151.47
		5	173.98
	X	1	55.486
		2	68.834
		3	142.7
		4	149.13
		5	174.23
	XI	1	55.518
		2	68.833
		3	149.12
		4	150.4
		5	173.91
	XII	1	55.434
		2	68.77
		3	149.22
		4	151.78

		5	173.97
Fixed- Pinned	IX	1	22.008
		2	38.282
		3	80.02
		4	116.88
		5	121.58
	X	1	22.004
		2	38.288
		3	79.975
		4	112.08
		5	121.44
	XI	1	22.011
		2	38.312
		3	80.044
		4	116.3
		5	121.59
	XII	1	22.039
		2	38.267
		3	79.977
		4	117.08
		5	121.62
Fixed - Free	IX	1	8.7129
		2	22.01
		3	30.967
		4	54.287
		5	80.033
	X	1	8.7232
		2	22.005
		3	30.64
		4	54.335
		5	79.986
	XI	1	8.7171
		2	22.012
		3	30.925
		4	54.343
		5	80.049
	XII	1	8.72
		2	22.041
		3	31.018
		4	54.302
		5	79.987

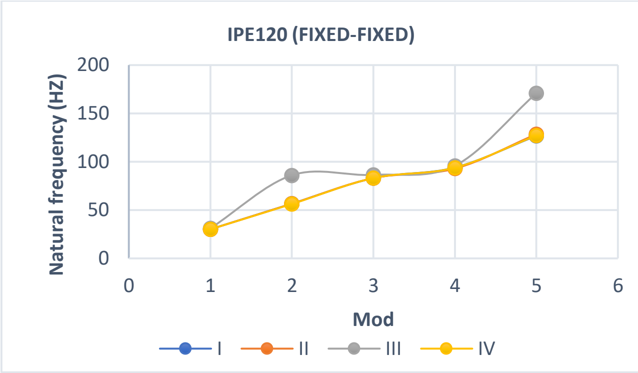


Fig. 14: Comparison of the natural frequencies for F-F with profile IPE 120 of castellated steel beams.

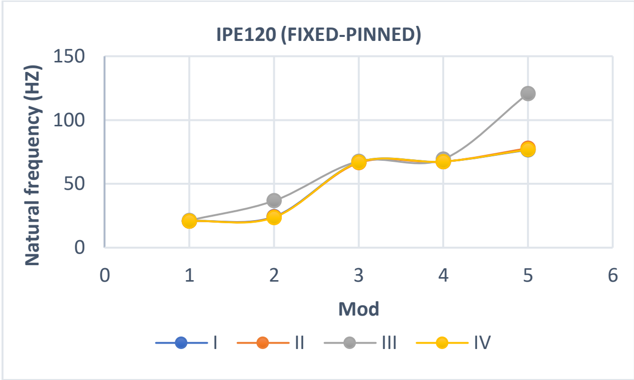


Fig. 15: Comparison of the natural frequencies for F-P with profile IPE 120 of castellated steel beams.

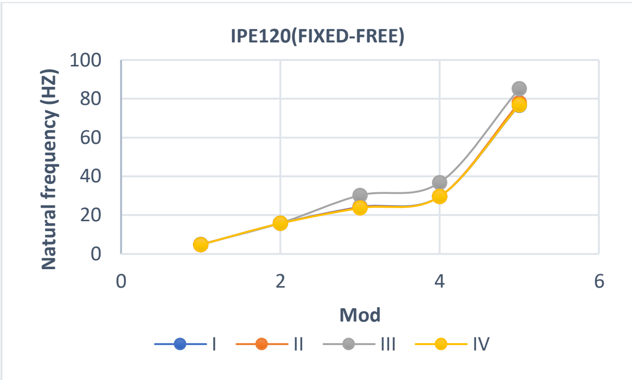


Fig. 16: Comparison of the natural frequencies for F-FR with profile IPE 120 of castellated steel beams.

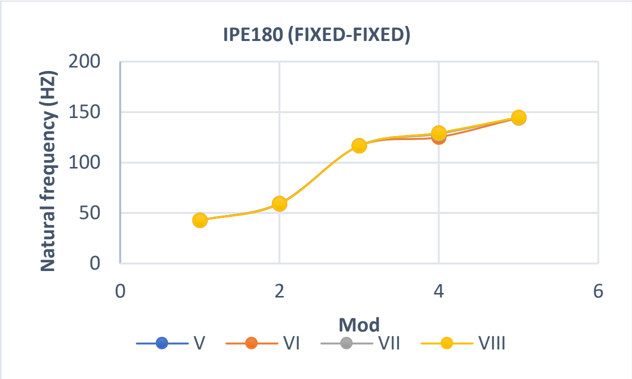


Fig. 17: Comparison of the natural frequencies for F-F with profile IPE 180 of castellated steel beams

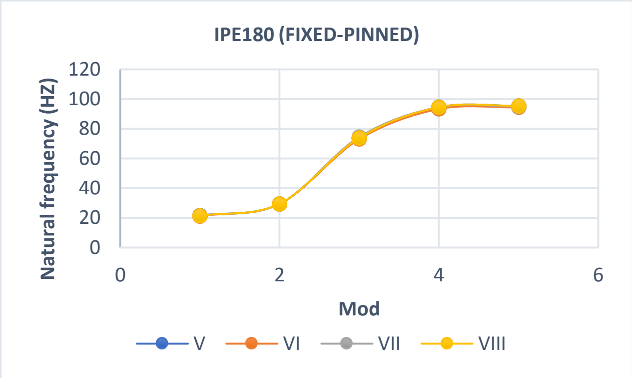


Fig. 18: Comparison of the natural frequencies for F-P with profile IPE 180 of castellated steel beams

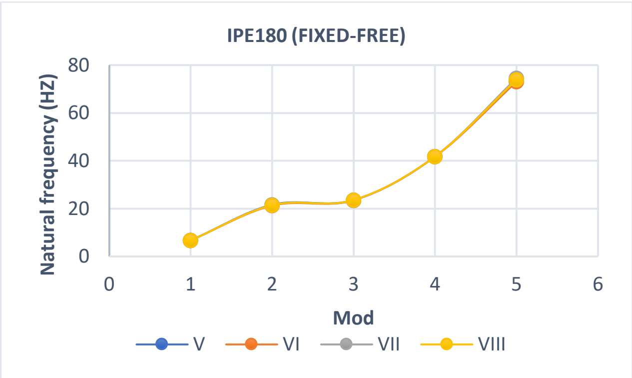


Fig. 19: Comparison of the natural frequencies for F-P with profile IPE 180 of castellated steel beams

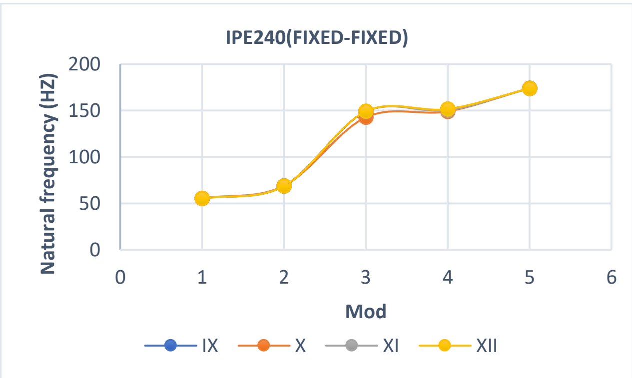


Fig. 20: Comparison of the natural frequencies for F-F with profile IPE 240 of castellated steel beams

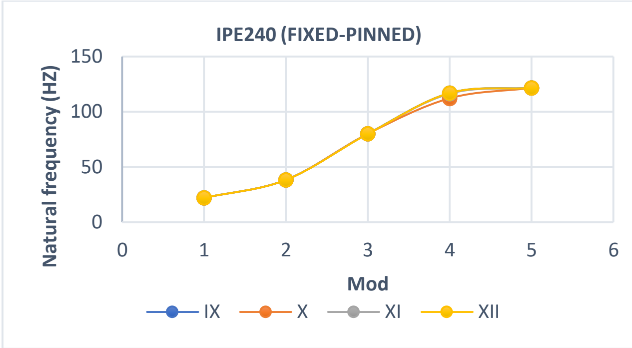


Fig. 21: Comparison of the natural frequencies for F-P with profile IPE 240 of castellated steel beams

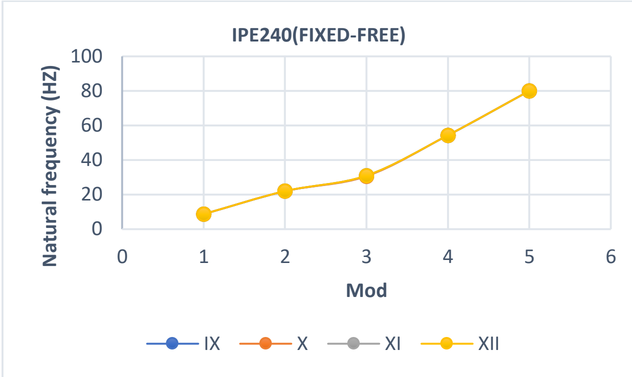
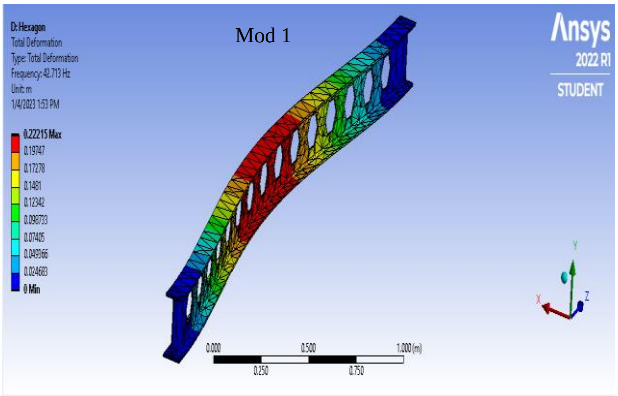
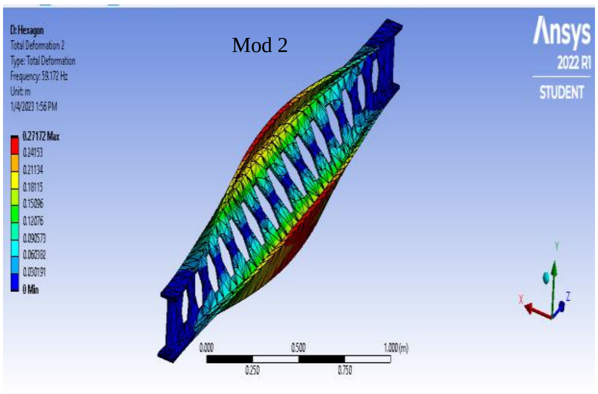
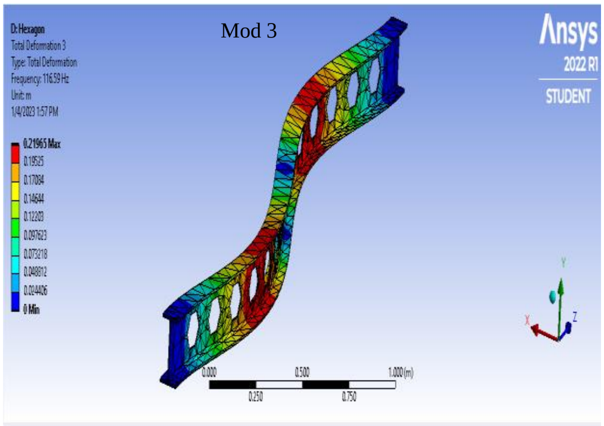


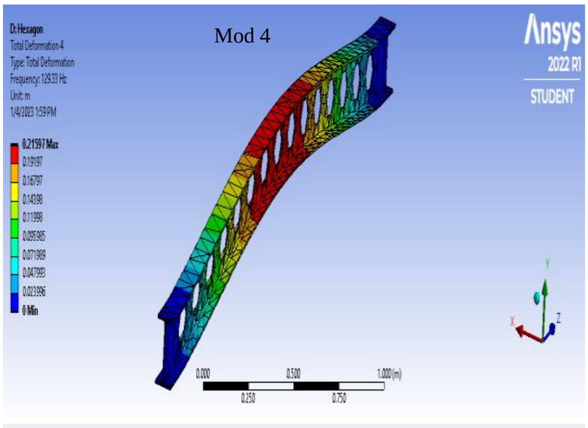
Fig. 22: Comparison of the natural frequencies for F-FR with profile IPE 240 of castellated steel beams

The mod shapes for Fixed-Fixed are presented for profile IPE180 case VIII in fig.23









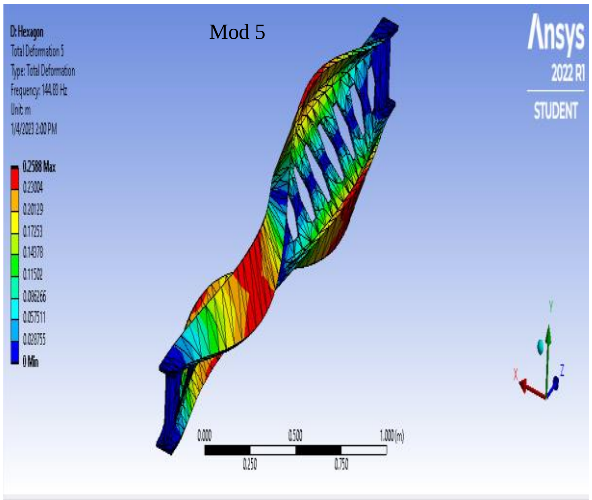
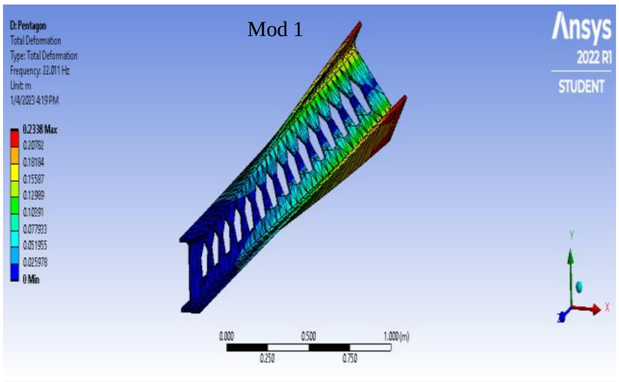
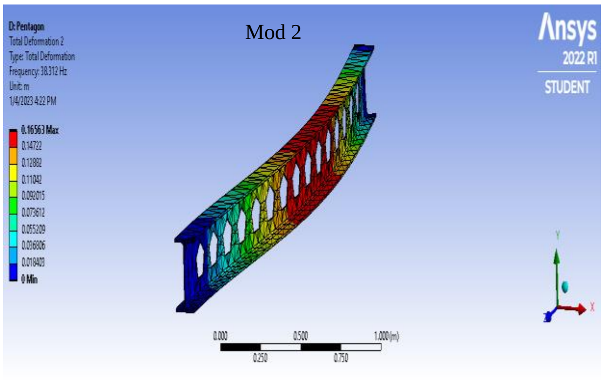
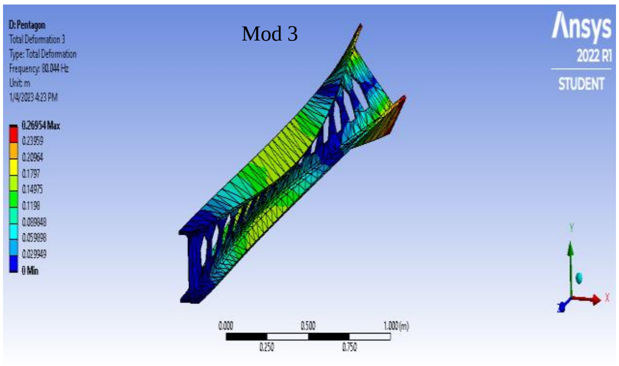


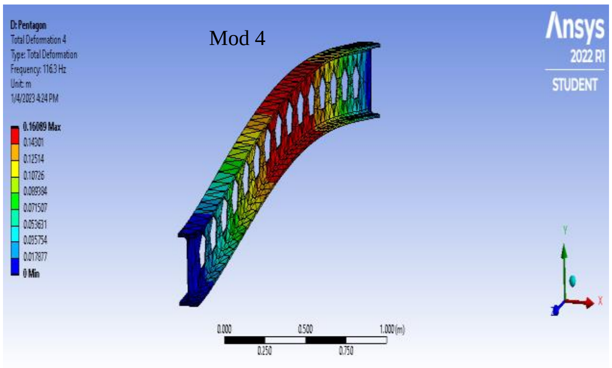
Fig. 23: The mod shapes for fixed – fixed castellated beam with profil IPE180 case VIII

The mod shapes for Fixed-Pinned are presented for profile IPE240 case XI in Fig.24









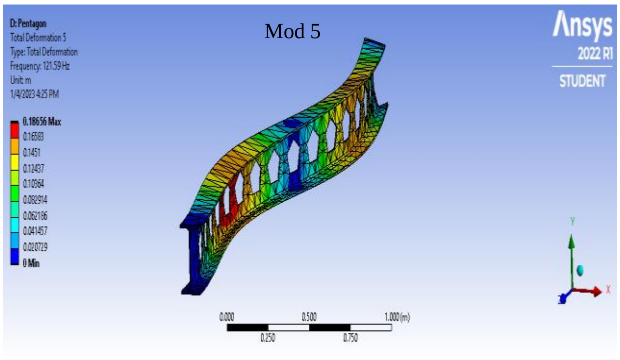
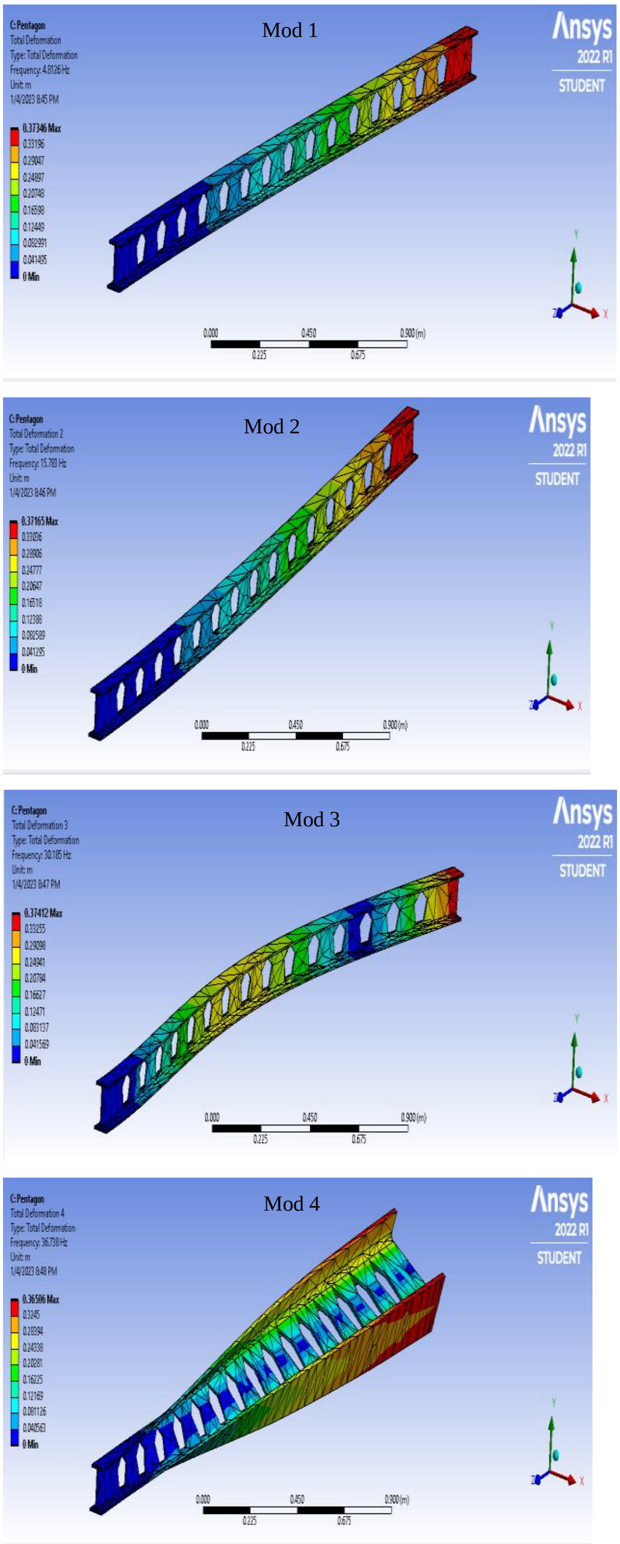


Fig. 24: The mod shapes for fixed – pinned castellated beam with profil IPE240 case XI

The mod shapes for Fixed-Free are presented for profile IPE120 case III in Fig.25



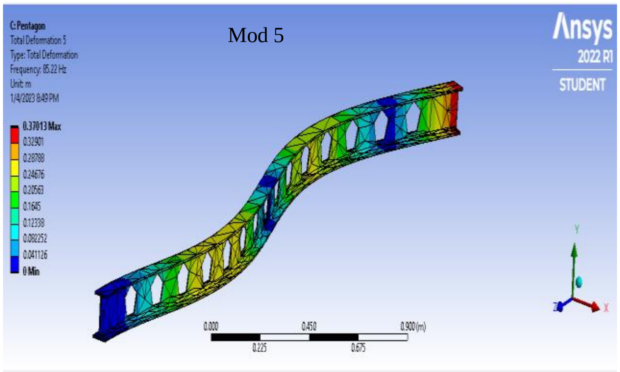


Fig. 25: The mod shapes for fixed – free castellated beam with profil IPE120 case III

4. Conclusions

In this study, the effect of web opening type on the static and dynamic behavior of castellated beams was investigated theoretically. The ANSYS Workbench program, based on the finite element method, was used in the analysis. Three-dimensional finite element models of the considered structural elements were established. Four different types of spaces were used: circular, square, pentagonal, and hexagonal. In order to perform the static and dynamic analysis of castellated beams made of IPE120, IPE180, and IPE240 profiles, fixed-fixed, fixed-pinned, and fixed-free boundary conditions are used. The most important results of the study are summarized below.

Static analysis:

The largest total displacements in the castellated beam occur in the case of a square web opening, and the smallest total displacements occur when a pentagon web opening is used in profile IPE120, while the smallest displacements occur when a hexagon web opening is used in other profiles. When hexagonal web opening geometry is used, the total displacement values of castellated beams with circular web openings are close to each other. As expected, the largest total displacements occurred in the fixed-free state.

Von-Mises and maximum shear stress values are affected by the type of web opening as well as the type of profile and support conditions. The largest von Mises stress values for IPE120 and IPE180 profiles occur when a hexagonal opening is used. The largest von Mises stress values for the IPE240 profile occur when a square opening is used.

The maximum shear stress values for the IPE 120 profile are largest in castellated beams with a hexagonal opening. For the IPE 180 profile, the largest maximum shear stress values occur when a pentagon opening type is used for fixed-fixed support, while the largest maximum shear stress values occur when a hexagon opening is used for fixed-pinned and fixed-free support. For the IPE 240 profile, the largest maximum shear stress with a square opening is used.

Dynamic analysis:

The influence of the web opening type and boundary conditions on the natural frequencies is investigated, and the following results can be concluded. Higher frequencies were recorded at F-F beams, and lower frequencies were recorded at F-FR beams. The type of web opening is essential for the value of the free vibration characteristics. The highest free vibration responses of IPE120 are observed while the pentagon web opening is used. For all other profiles it has seen the geometry of the web opening does not have any significant influence on the free vibration frequencies. Also the amplitude of vibrations is not effected by the type of the web opening.

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Research Papers should not exceed 12 printed pages in two-column publishing format, including figures and tables.

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Equations:

Number equations consecutively with equation numbers in parentheses flush with the right margin, as in (1). To make equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use an dash (–) rather than a hyphen for a minus sign. Use parentheses to avoid ambiguities in denominators. Punctuate equations with commas or periods when they are part of a sentence, as in

$$\mathrm{C = a + b} \tag{1}$$

Symbols in your equation should be defined before the equation appears or immediately following. Use “Eq. (1)” or “equation (1),” while citing.

Figures and Tables:

All illustrations must be supplied at the correct resolution:

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In addition to using figures in the text, upload each figure as a separate file in either .tiff or .eps format during submission, with the figure number.

Table captions should be written in the same format as figure captions; for example, “Table 1. Appearance styles.”. Tables should be referenced in the text unabbreviated as “Table 1.”

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Books

[1] J. Clerk Maxwell*, A Treatise on Electricity and Magnetism,* 3rd ed., vol. 2. Oxford:Clarendon Press, 1892, pp.68-73.

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[2] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface”, *IEEE Transl. J. Magn. Japan*, vol. 2, pp. 740-741, August 1987.

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12	Main text, equations, Authors’ names, [a]		*Subheading (1.1.)*
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• All figure captions (supplied in a separate document)

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Keywords- Keyword1; keyword2; keyword3; keyword4; keyword5.

2. Introduction

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$$C = a + b \quad (1)$$

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3. Figures and Tables

3.1. Figure Properties

All illustrations must be supplied at the correct resolution:

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Figure 1. Engineering technologies.

Table captions should be written in the same format as figure captions; for example, "Table 1. Appearance styles.". Tables should be referenced in the text unabbreviated as "Table 1."

Table 1. Appearance properties of accepted manuscripts

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12	Main text, equations, Authors' names, Section titles		*Subheading (1.1.)*
24	Paper title		

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Editor also informs authors about processes of submitted article by e-mail. Each author may also apply to Editor via online submission system to review papers related to their study areas. Peer review is a critical element of publication, and one of the major cornerstones of the scientific process. Peer Review serves two key functions:

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8. Conclusion

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Acknowledgements

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References

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[12] IEEE Standard 519-1992, Recommended practices and requirements for harmonic control in electrical power systems, The Institute of Electrical and Electronics Engineers, 1993. (Standards and Reports)

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