International Journal of Engineering Technologies (IJET)

Volume:7
No:3
September 2021

Printed ISSN: 2149-0104
e-ISSN: 2149-5262

International Journal of Engineering Technologies is an international peer–reviewed journal and published quarterly. The opinions, thoughts, postulations or proposals within the articles are but reflections of the authors and do not, in any way, represent those of the Istanbul Gelisim University.

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INTERNATIONAL JOURNAL OF ENGINEERING TECHNOLOGIES (IJET)
International Peer–Reviewed Journal
Volume 7, No 3, September 2021

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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 27th 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 27th 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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https://dergipark.org.tr/en/pub/ijet
Printed ISSN: 2149-0104
e-ISSN: 2149-5262

International Journal of
Engineering Technologies
IJET

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Volume 7, No 3, September 2021

International Journal of Engineering Technologies, IJET

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Direct Displacement Based Design of RDC Frame-Shear Wall Structures

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Received: 15.10.2020 Accepted: 14.08.2021

Abstract- A large part of Turkey's urban region is located in the seismic prone zone and in terms of population, the majority of densely populated cities are located close to near-fault regions. It is very important to determine the behaviors of structures against external forces after destructive earthquakes. Structural and non-structural damages that occur during the earthquake usually arise from lateral displacements occurring in the structural system. This is why, in recent years, the displacement-based design has become more important when compared to the force based design. In this study, the Direct Displacement Based Design method under earthquake forces are explained. The process steps of this method on a frame-wall structure are clarified. The dynamic behavior of a moment resistant structures and a combined system with shear walls are compared. The finite element method used to analysis of reinforced concrete building models. Some model with moderate and high vibration period is adopted for dynamic analysis. An arrangement of the shear walls is changed in story plan of models. The dynamic analysis has shown quite different response among the structural systems. The difference in dynamic behavior is coming from the interaction of dynamic response between shear walls and moment resistant frames. Furthermore, the important role of shear walls displacements in transferring lateral loads is clarified with numerical examples. The positive role of RC shear walls on the combined structures under earthquake forces has been emphasized.

Keywords: Displacement based design, interstory drift, shear walls, finite element method

1. Introduction

Considering the earthquake reality; the necessity of designing more reliable and strong constructions cannot be ignored. This is where the performance of displacement-based performance comes into play. Structural investigation and design based on design provisions have been elaborated and improved during the investigation of strengthening structures that are primarily concerned with determining the earthquake resistances against earthquake hazards more realistically and not providing adequate safety. It is also important to determine which method is suitable for designing earthquake resistant structures. Displacement-based design methodology ensures that damage to the structure can be determined in a more realistic way. This research is gaining value at this point. This method, which has been mostly studied over the last years, is enriched by putting new researches on each passing day [1,2].

The displacement ductility, strength and rigidity criteria required to design an earthquake resistant building are described. In order to investigate the relative story drifts of the wall - frame systems numerical examples are given and building analyzes are made. The calculation methods are shown step by step to explain how to analyze the sample buildings. The 6 and 12 stories have been applied to the structures with six different story plans, stiffness distribution pattern is created and the numerical calculation of the base shear forces is shown. The wall-frame systems are totally superimposed over shear-wall or completely frame systems. Story displacements and relative interstory drifts analyzed by using the finite element analysis IDESTATIC program [3] and mode superposition method are found. Reinforced concrete walls also compensate story displacements due to the rigid structure. This reduces the total displacements throughout the building height. According to analysis result the relative interstory drifts and story displacements that showed the positive effect of the compared shear- walls on the system and checked that they did not exceed the targeted rates.

Recent developments in an earthquake and structural engineering have brought a different approach and energy to these views, which are known as common engineer approaches. Since 1995, as a result of earthquake and structural engineering, it is determined that the concrete column shortening story and building lateral displacements from the principle of "Strengthening (or Force Based) Design" based on the values of bending moment, normal force, shear force, and seismic performance values, (or displacement, change of shape, displacement) of buildings based on their values, based on the values of the unit elongation and the shortening of the equipments and the seismic performances of the buildings can be mathematically determined. Structures generally do not provide clear information on the Force-Based Design approach. Although these codes give some information on the damage status of the building elements, they give only very limited information on the damage status of non-structural elements and systems. Displacement Based Seismic Design, a new concept in seismic design of constructions, is a reliable approach that can provide more detailed information about the performance levels of both structural and nonstructural elements.

Since they are the main elements providing lateral stiffness, reinforced concrete shear walls and their behavior are of vital importance in ensuring structural safety under lateral altering. The structural safety of reinforced concrete buildings under lateral effects is ensured by reinforced concrete shear walls. The system, which is designed with frame and shear wall carriage together and called shear wall-frame system, is designed in order to meet the considerations of covering a significant part of the lateral forces coming into the structure through the shear walls.

In this study, a linear displacement-based design procedure is described for shear wall-framed structures. In its most general form, shear walls are elements carrying lateral loadings. The direct displacement-based design method describes the design of shear wall-frame type structures based on displacement and the effect of shear walls on displacement. In direct displacement-based design method based on shear wall-framed systems. Instead of a multi-degree-of-freedom structure, a single-degree-of-freedom analysis method that performs the solution together with the structure is used. The aim of this method is to show the displacement profile damping components for the shear wall-frame type structure as a single degree of freedom system and make the system design as applicable as possible by reducing the base.

In this study, it is aimed to evaluate how the effect of shear walls in reinforced concrete buildings or the contribution of lateral forces is clarified on the basis of the Direct Displacement-Based Design method. For this reason, five different reinforced concrete moment resistant systems have been analyzed. The building consisting of 6 different types of reinforced concrete shear wall-frame system with 6 and 12 stories is analyzed. IDESTATIC platform is used in evaluating earthquake performances of structural models. As a result of the analysis made by the Mode Contribution Method, the displacement values and the effects of the shear walls on the design of the structure are observed. The displacement values are calculated and compared for the earthquake ground motion effect with a probability of exceeding 10% in 50 years. In the calculated target displacement value, the plastic rotations of the column, beam, shear walls are firstly calculated, then the relative interstory drifts between two consecutive stories are calculated. The relative interstory drift results are compared with the limit values given in the current earthquake regulations.

The concepts and criteria of displacement-based design are described in detail in specifications such as ATC 40 [4], FEMA 273 [5], FEMA 356 [6], FEMA 440 [7], ASCE / SEI 41 [8], CEN (EC8) [9], TEC [10] and TBDY [11]. These regulations, which have a lot of similar features and benefit from each other, briefly describe the static calculation bases and criteria that take into account the plastic movements under earthquake forces of buildings and explain the related performance levels to be used for determining the possible damage rates of the structural members following the dynamic analysis and their evaluation methods.

Nowadays there are many researches on displacement-based design are available in the literature: Shibata and Sözen [12] presented the substitute structure method for ESD systems. Replacement Method for Reinforced Concrete Structures was a method used to determine the design spectrum and design forces of earthquake motion. This method has been used by Priestley [13] and Priestley [14] to create the "Direct Design by Displacement" method that is using in practice. The capacity spectrum method given in ATC-40 [4] modified by Hong and Cho [15].

Priestley et al [16] described the basic principles and main outcomes of the displacement-based design. How to convert complexity systems multiple degrees of freedom into an equivalent single degree of freedom system. A method describing the modal motion of symmetric and asymmetric buildings was presented. 6, 12 storey reinforced concrete structures were applied on the method in the building type results were investigated. This method was called the Direct Displacement Design (DDED) [17].

Kowalsky et al. [18] proposed displacement based design method when designing reinforced concrete structures and bridge piers. Single degree of freedom structures and bridge columns are examined and compared based on displacement. They take pier strength and stiffness as the basis, and they regard the strength and stiffness in the method as a result of the method, not variable. The DDBD procedure reinforced concrete frame and steel supports was investigated. Three identical structures were made with different heights. To verify the procedure of such structures, a nonlinear time history analysis was applied. The results obtained from the nonlinear time history analysis shown that the DDBD procedure was very effective for the seismic design of such structures [19, 20]. Another application of the Direct Displacement-Based Design (DDTT) approach as one of the PEST procedures, has been demonstrated by Karimzade and Aktas [21]. Relative story drift ratios were used to describe performance levels at given earthquake levels. Capacity design principles were also followed to ensure ductile behaviors of plastic hinges on the exterior beams from the columns. Analysis has been carried out to check that the relative interstory displacements do not exceed the targeted rates.

Abhyuday [22] studied on the importance of structural displacement during the design of structural and non-structural elements, also presented a fundamental description of the Direct Displacement Based Design (DDBD) procedure (as proposed by Priestley [16]) together with its advantages and limitations over the conventional Force Based Design (FBD) method. The various performance levels were investigated and accordingly a methodological statement of the DDBD method was dedicated for computing the amount of base shear. Unlike FBD, in DDBD the limit states were not controlled, rather those were applied as an input data. Accordingly, it was indicated that the DDBD was simple and more economical than the conventional FBD method. It is believed that in the coming years the DDBD method will be adopted in whole and that it will be used as a solemn alternative method by its simplicity and advantages.

Lopes et al [23] used a way pushover analysis, so-called N2 method, for the seismic vulnerability evaluation of various building typologies. The opinion of reversing the N2 method in a direct displacement- based design was not new and currently adopted in the Annex B of Eurocode 8. the procedure proposed in this paper offers an easy alternative form to calculate the ratio of the seismic action regarding to any performance level and to specify the target displacement without the need for an iterative process. The procedure proposed will provide the opportunity to evaluate graphically of how a structure will behave when exposed to strong ground motion.

Yan and Gong [24] conducted an adaptive pushover analyses for sixty-six RC frame buildings with characteristics in order to calculate the distribution of lateral displacement, and in turn an altering law of plastic hinge distribution and deformation mechanism. As result, displacement profile expression in design considering multiple performance objectives was proposed. A practical displacement-based framework for seismic design of flexible-base structures subjected to near-fault pulse-like ground motions was presented by Lu et al [25]. An equivalent fixed-base single degree- of-freedom oscillator is adopted to capture the salient features of an actual soil-structure interaction (SSI) system in order to facilitate the design process. Two step-by-step direct-displacement based design (DDBD) procedures based on compatible inelastic spectra and equivalent linearisation were introduced. The results of this study suggest that the procedure based on inelastic design spectra, in general, provides a better design solution than using an elastic linearisation method, especially when structures were designed with a higher ductility demand.

In this study, the principles of design for displacement are explained and the stages of direct displacement-based design of shear wall-framed structures are explained steply. The basic concepts including performance-based calculation methods in current provision are investigated. Following evaluation of in the behavior displacement ductility, the effect of shear walls on reinforced concrete structures in the design for displacement is defined as the elements which increase the lateral stiffness and numerical examples are given on five buildings with 6 and 12 story shear wall-frame system. Shear wall-frame type structures are given by direct displacement-based design method; it is aimed to show the effects of lateral walls on shear walls. Idestatic V.8 analysis platform has been analyzed on building models. As a result of the analyzes; the examples are based on some assumptions and the solution has shown that the existing shear wall-framed structures reduce the displacement results and the relative story drift of shear wall use.

2. Modeling and Method of Analysis

Displacement-based design, as the basic idea; the form of the seismic design which is the basis of the method considered in the calculations of the displacements (deformations) in the structures. In direct displacement-based design method based on shear wall-framed systems; instead of a multi-degree-of-freedom system, a single-degree-of-freedom system analysis method that performs the solution with the structure is used. The aim of this method is to develop the displacement profile damping components for the shear wall-frame type system show as a single degree of freedom system and to make the system design as applicable as possible by reducing the errors.

The prominence of the representation of an equivalent single degree of freedom; the inelastic properties of a multi-degree-of-freedom structure under the earthquake forces can be incorporated into a simple model design. The effective displacement of the structure, the equivalent viscous damping function, the effective period and the design behavior spectrum are obtained using an equivalent TSD system. The displacement behavior spectrum can be calculated using different stiffnesses and masses in the TSD system. Therefore, the equivalent system approach should be used together with the displacement behavior spectrum. In a subsequent step, the effective stiffness can be calculated using the effective period. When the calculation resultant effective stiffness is known, the base shear force can be calculated. As a result, the multi-degree of freedom structure can be designed by distributing base shear forces over the building height.

Shear wall-frame type buildings are structures that use both framed and shear walls to resist earthquake motions. A special design methodology can be used for a structure of this type is required. Generally, shear wall-frame type structures are known as combination of two-system. Because the behavior of such a designed carrier system is quite different from the systems consisting of only frames or only shear walls. While the differences in the calculations, usually in the designs, are attributed to the interaction of the frame systems, the shear walls did not take up enough space in practice. The combination of shear walls and moment resistant frames combined with the building system is a very efficient and useful way to resist earthquake forces. The shear walls and frames used together to provide significant advantages over systems that consist entirely of shear walls or frames. Particularly shear walls are very convenient elements for controlling relative inter story drifts.

Shear walls limit the deformation of upper stories of buildings are limited. Reduces the total number of placements that the structures are experiencing. From an aesthetic and functional point of view, the frames provide a wide range of space for not restricting their use. They are, however, useful elements for protecting against fire and forming stairs in shear walls [26].

For shear wall-frame systems, shear wall rigidity should be reduced in the lower sections of the shear wall due to the equivalent system method. Base moments which are formed in the ground story columns are calculated according to the base shear force value of the column and the shear walls. After the shear wall moments are calculated from the shear wall-column stiffness ratio, such that all the data required for the static analysis is calculated.

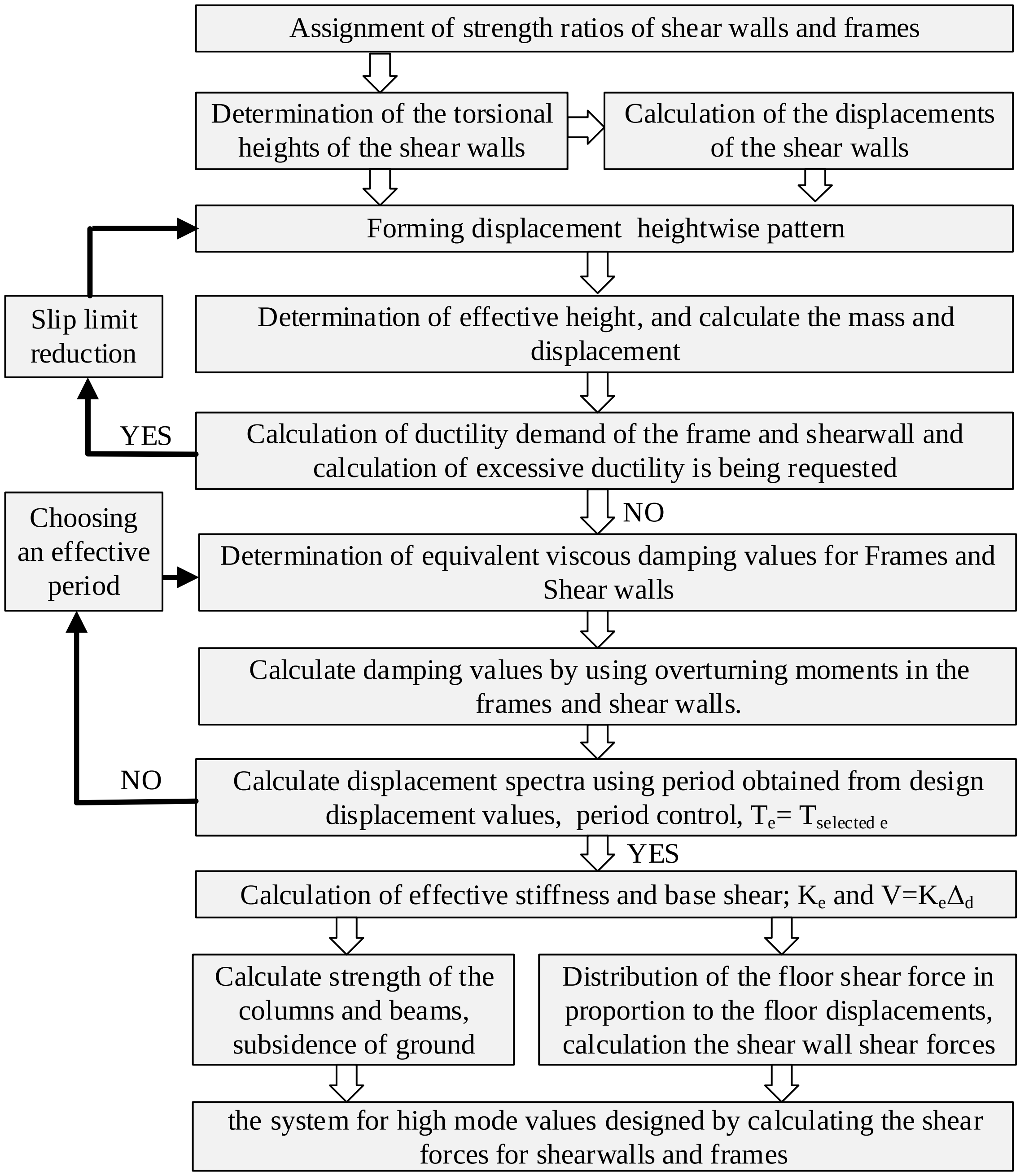


Fig. 1. Flow chart of the proposed design process for Shear wall – moment resisting frame system [17, 27].

The contribution to tolerated forces the continuous columns about weak beams is very limited. The capacity requirements must be met by the columns on the other axes.

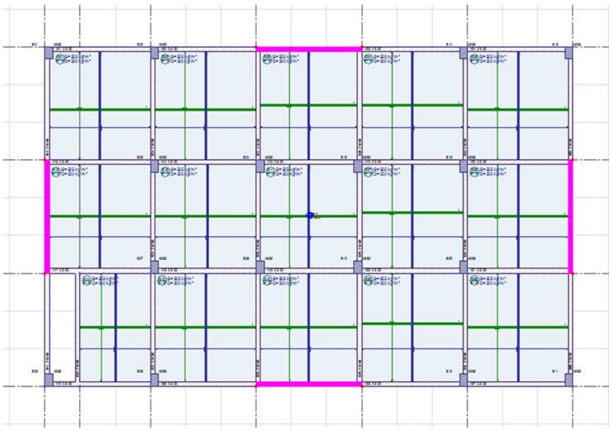
The contribution to the strength of the structure of the columns on the (weak) axis with the beam discontinuity is very small. The stiffening and stiffness requirements must be fulfilled by the columns on the other axes

3. Analysis of R/C frame-coupled wall structural models

In this section, reinforced concrete buildings built with a shear wall-frame system with the same story plans of 6 and 12 stories and with/without shear walled buildings with 6 stories with different story plans are subjected to static analysis, relative interstory displacements are calculated and distributed profiles of displacements over the height are created. Analyzes are made using the IDESTATIC 8 structural analysis program. The shear walls placed opposite each other at the mid-axis of the structures are connected to each other by beams. In addition, the effect of the shear walls placed at corner points on different story plans has been examined separately. The interaction between the moment resistant frame and the shear-wall of the importance of structures connected together by the beams is important. The level of life Safety is considered as the story displacement limit.

3.1 Structural Properties of Structural model

The structural properties of building models are defined here; the story dimensions are 30 x 18 m, the story heights are similar and equal to 3 m in all stories. The moderate and high rise building models (6 and 12 stories) are used. The shear walls with the different arrangement are considered as well. Therefore, five different models are adopted to evaluate displacement demands. Since the buildings are thought to be residential buildings, the building importance coefficient is used as I = 1. It is built in Istanbul in the 1st seismic zone. Local ground class Z4 type and C group soil are adopted according to TEC 2007 provisions. According to Z4, the spectrum characteristic periods are TA = 0.20 and T_B = 0.90. The concrete grade is C25 and the S420 steel grade used for longitudinal reinforcements. The cross-section area of the columns with 45 x 65 cm. All the beams in the building are the same size with 25 cm / 50 cm, the 15 cm slab height even though the openings are large.



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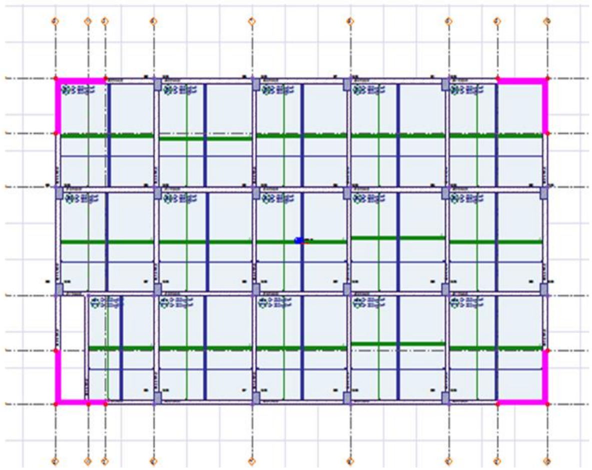

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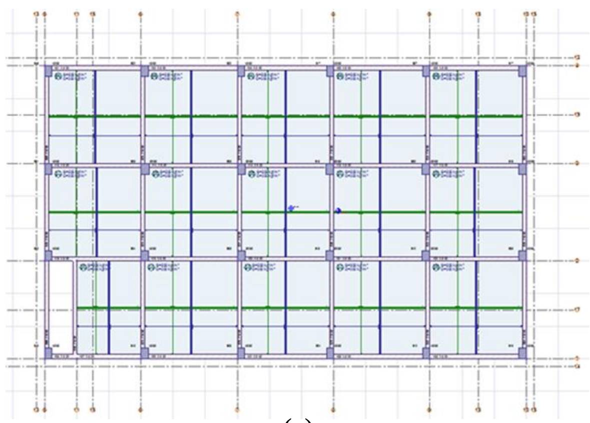
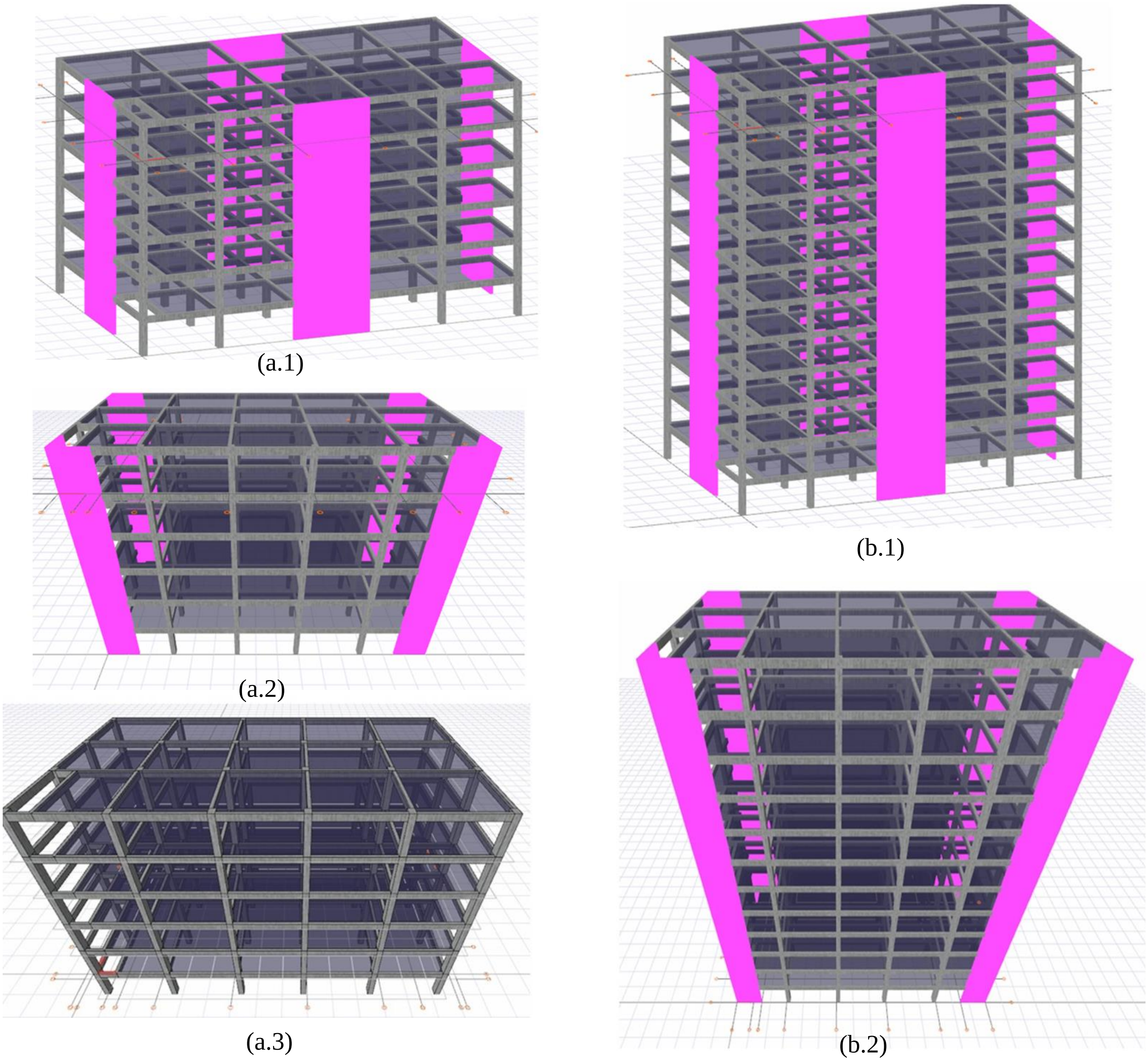


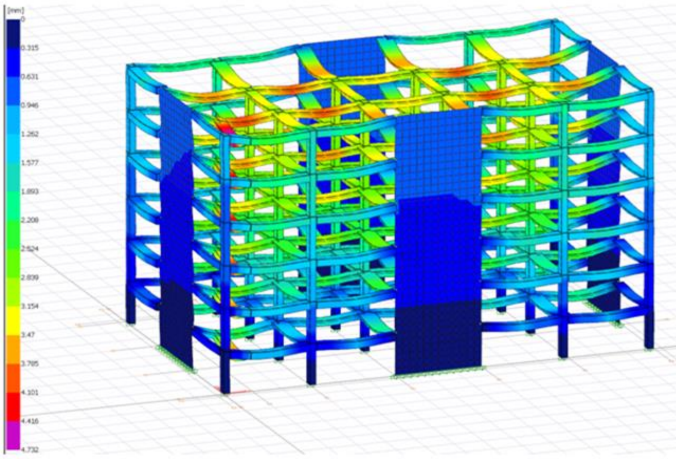
(c)

Fig. 2. Plan view of structures with and without shear wall



6 story Building 12 story Building

Fig. 3. Schematic 3D view of 6 and 12 story RC buildings



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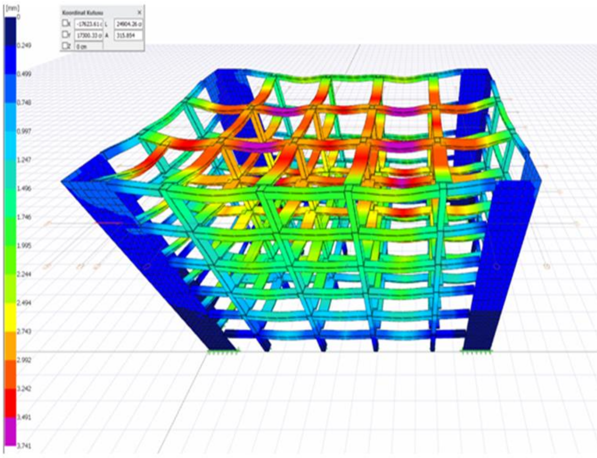
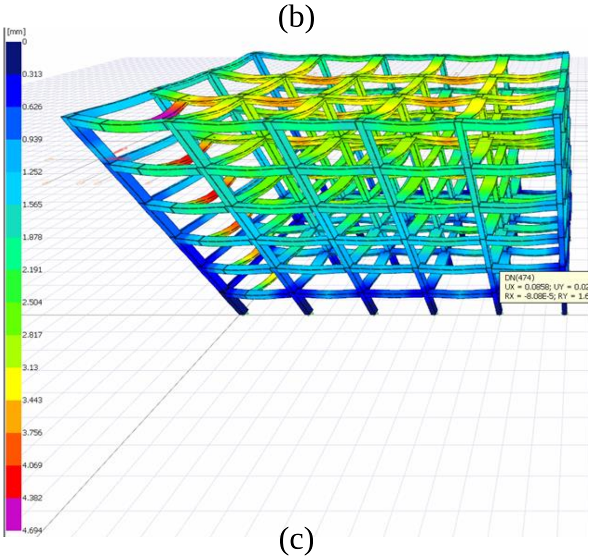


(b)

Fig. 4. Deformation of 6-story structural system with and without shear Wall



(c)

Table 1. The values of base shear force, displacements and relative interstory drifts for 6 and 12 story buildings with a different story plan

	6 Story building	12 Story building
Length of shear wall (cm)	600	600
Shear wall thikness (cm)	25	25
Beam dimensions (cm)	25*50	25*50
Column dimensions (cm)	45*65	45*65
Story height (m)	300	300
Total weight of building (kN)	2702	5552,39
Total mass of building (ton)	275,4	561,20
Total building height (m)	18	36
Slab thickness (cm)	15	15

4. Dynamic Analysis results

The dynamic responses of 6 and 12 storey building models with shear wall - frame system and 6 storey moment resistant frame system listed in Table 1. For shear wall systems; the analysis results for the cases where the shear walls are placed in the central axis of the building and placed at corner points of the building are given in detail.

It can be said that the shear walls placed symmetrically on the exact middle point of the building with movement from the table, limit the displacements and drifts more than the corner points. When the number of stories changes from 6 to 12, displacements and displacements in buildings are changing in such a way that the displacements are increasing at a level that can be tried 1 to 6 times. Relative inter story is increasing in displacement, but the ratio remains as 1 to 3 times. When the shear walls are removed from the center, it is seen that the displacement and interstory drifts are very high when looking at the 6 story building. This shows us how much the shear walls balance the relative story drifts in the combined systems.

Shear wall curvature demands are high and story drifts must be reduced to ensure that the design material stress limits range in 12-story buildings.

Shear wall - Final design forces for framed structures may depend only on the mass and story stiffness of the base shear force; demonstrates that design can be simplified to a significant amount without changing its mood. For the structure being analyzed, the longitudinal reinforcement ratios are used to improve strength capacity.

Under the lateral seismic forces, the most important indicator of building rigidity is the rate of relative displacement in which an individual element has its own rigidity and interstory drifts. In the Earthquake Regulations, relative to the features described as relatively displaceable during the earthquake. For one of the two earthquake directions perpendicular to each other, the torsional irregularity coefficient, which is the ratio of the highest relative story drift on any story to the mean relative drift on that story in the same direction, is greater than 1.2, is called Torsional Irregularity. Care should be taken to prevent torsional irregularities, such as shear walls, etc., where rigid support system components are installed to increase torsional stiffness of the load carrying system [28].

As a result of the analysis made in the sample building, the data belonging to the structure are obtained; The details of the shear walls and columns of the 6 and 12 storey buildings are shown in Figure 1 and Table 1. Section dimensions and reinforcement detail are listed in Table 1.

Relative interstory drifts and story displacements are calculated for models with similar story plan, same story height but for twelve-story structure model. As a result of the analysis with Mode Combination Method, it has been observed that the displacement approach based on the displacement based design approach is very successful at the limit point. Interstory drifts are directly related to deformations, so they show a similar tendency.

Since the shear walls are restrictive elements for lateral displacements, the displacement values of the buildings are compared while investigating the behavior patterns of the different systematic buildings. The addition of shear walls to the system greatly reduces drift.

When the mentioned structure is evaluated in terms of relative story displacements for both systems, it is seen that story drifts in the shear wall system are balanced to a considerable rate. Story drifts that occur especially on the ground story are reduced. We can say that the shear walls are the elements that reduce the displacement of the relative interstory drift by their rigidity.

As a result of our analyzes on five different buildings with different story plans; how the use of shear walls, the location of the shear walls, and the relative story drift rates of the stories are affected. As can be seen in Figure 2, symmetrical systems in which the shear walls are located mutually in the middle axes according to their apparent shear force values are the most reliable systems in terms of tolerating relative story displacements. Similar results are obtained for 6 and 12 storey buildings, and the displacement values are more limited than the other systems. In the moment resistant frame system, the relative story displacement is similar for both the 6-storey and 12-storey buildings, although it achieved the base shear force. This clearly shows that the shear walls are very effective elements in limiting the relative interstory drifts.

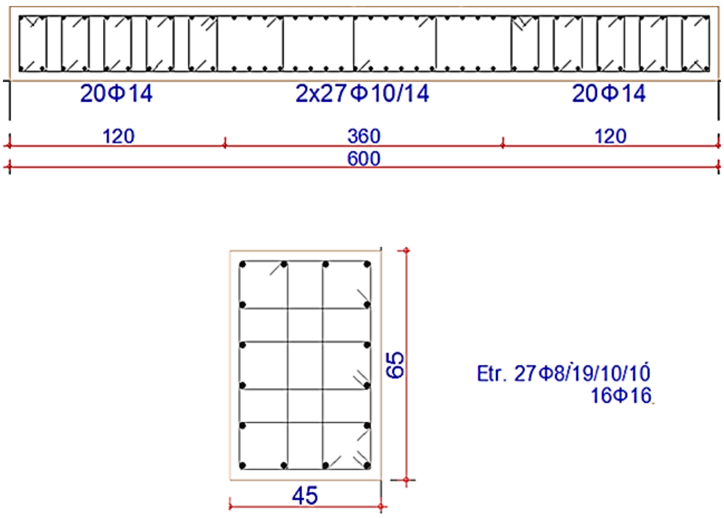


Fig. 5. Dimension and reinforcement detail of shear-wall and column used in 6-storey building model

Table 2. The values of base shear force, displacements and relative interstory drifts for models with different story plan and a different number of stories.

	6 Story shear wall at middle	6 Story shear wall at corner sides	6 Story without shear walls	12 Story shear walls at corner sides	12 Story shear walls at middle
Total weight of structure (ton)	2759,35	2795,74	2617,23	5552,39	5498,68
Base shear force at X direction (kN)	424,51	430	402,65	772,60	766,12
Displacement (mm)	9,17	11,10	26,20	61,70	57,64
Maximum interstory drift (mm)	12,20	14,87	43,07	42,21	38,37

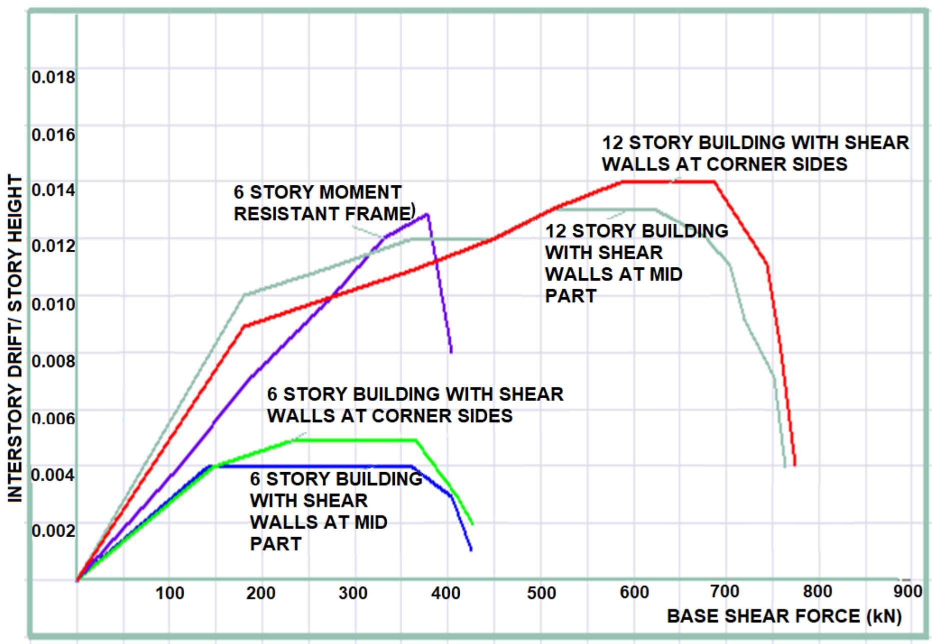


Fig. 6. Shear Stress and interstory drifts values on the basis of the load carrying System

5. Conclusions

The displacement-based design method used to develop the displacement profile damping components for the shear wall-frame system represent as a single degree of freedom system and to make the system design as applicable as possible by redacting the drawbacks. The analyses results showed that; the displacement-based seismic design method provides perfect control of displacement and a reliable approach to interstory drifts in shear wall-framed structures. This design method is applied to 6 and 12 storey building with shear wall - frame system. The Finite element IDESTATIC 8 analysis platform is adopted for structural response analysis. Displacements and relative story drifts are handled separately for shear wall and moment resistant frame cases in the examples and where the shear walls are placed at different positions. The variation in story plans and layout pattern of shear walls are adopted to change the distribution of story rigidity and story strength of building along the building height. Interstory drifts rates are used to represent performance levels under the ground motions. Peak displacements, base shear forces are investigated as well. The structure is increased in effective periods as the building height increases due to the number of stories.

In this thesis study, six and twelve storey reinforced concrete buildings are used in determining the seismic performances of the system. Different buildings are analyzed as shear wall-frame system by placing shear walls in X and Y directions. As a result of the analysis, the performance levels are determined. Table 2 gives about relative story displacements and twisting of structures. Shear walls used in shear wall-frame system are used in X and Y direction. These shear walls contribute to the lateral load carrying capacity of the system. In addition, the contribution to the balancing of relative story displacements is large. As a result of the analysis, it can be said that the shear walls placed symmetrically at the exact outer mid-point of the building are more restrictive than displacements and displacements compared to those placed at the corner sides. In this case, the stiffness due to shear wall lengths should also be considered. When the number of stories changes from 6 to 12, displacements and interstory drifts in buildings with the same number of stories is changing in such a way that the displacements are increasing at a level that can be tried 1 to 6 times. Relative stories are increasing in displacement, but the ratio remains as 1 to 3 times. When the shear walls are removed from the center part, it is seen that the displacement and the displacements are very high when looking at the 6 storey building. This shows us how much the shear walls reduce relative story drifts in the combined systems.

In the determination of building performance gain from nonlinear static analysis methods, the performance levels of the structure are interpreted taking into consideration the section turn, torsion and relative interstory drift values in the system to be used in the element to be used. For the shear wall-frame type system, considering the rotations occurring in the plastic joints; the performance level of the structure remains in life safety level while the level of performance is in the level of performance of safety but closer to the level of immediate use in view of the relative story drifts that occur in the structure. As a result, it is observed that the structure of the section rotations formed for the analyzed structures is more effective in determining the performance than the relative story displacement. Plasticizing in columns usually occurs at the lower tips of the columns on the ground where the largest earthquake moments occur, but not for beams. Plastic joints spread in the structure, they can be seen at different points. Shear wall- in a frame with a frame system, tendons tend to plasticize mostly in beams that transmit moments to the shear walls.

Relative story displacement rates are also found to be smaller in shear wall-frame type buildings as they are lowered to the lower stories only by frame type structure. It is an inevitable requirement to use reinforced concrete shear walls to design buildings resistant to seismic forces. When shear walls limit lateral displacements, they significantly reduce relative story displacements. For future works, design for shear wall-frame systems can be designed to be in the inner-middle part of shear wall structure system.

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Laboratory Evaluation of Undrained Shear Strength of a Soft Fine Grained Soils

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Received: 07.06.2021 Accepted: 15.12.2021

Abstract- The determination of undrained shear strength of soils is commonly achieved using triaxial testing in which specimen is carefully prepared before testing to maintain its original field condition. However, for soft soils preparing and handling specimens without causing any disturbance is a difficult job and may not always be successful. Other laboratory testing techniques can be adopted provided they can produce reliable results for such cases and can overcome the problem of pretest preparation process and hence avoiding any alteration of sample field condition. Extensive laboratory investigation on a soft marine soil recovered from sea bed offshore of Benghazi city, the testing program involves investigation of the basic geotechnical properties, focusing specifically on the determination of the undrained shear strength of such soils as determined by both the conventional unconsolidated undrained triaxial testing (UU) and the simple laboratory vane shear testing device (Miniature shear vane MV). The resulting shear strength obtained by UU-triaxial test, and resulting shear strength measured by Miniature shear vane MV were examined, compared and discussed on the light of other research works. Furthermore, the problems faced during testing soft samples in triaxial apparatus was also presented. The resulting undrained shear strength obtained by UU-triaxial test was found generally lower than that produced by Miniature shear vane MV which is attributed to sample disturbance before testing in triaxial. The study also demonstrates that despite of high scatter, the undrained shear strength obtained by MV can be reasonably comparable with the results of other investigations on soft soils.

Keywords: Soft soils; Undrained strength; Index properties; Laboratory testing.

1. Introduction

Soft soils usually a source for many problems to geotechnical engineers, because of their low shear strength and liability to exhibit large deformation. The correct evaluation of shear strength is very important for achieving safe design and avoiding the incidence of instability.

Measurement of undrained shear strength in the laboratory is commonly made using triaxial testing on a cylindrical specimen directly recovered from the field after they have been subjected to certain sample preparation to fit with test apparatus. Triaxial test is relatively expensive and time consuming, furthermore soft soils are susceptible to certain degree of disturbance during sampling, handling and other pre-test process [1,2].

The adoption of simple testing devices may be a possible alternative for evaluating undrained shear strength of soft soils, with respect to cost, time and problems of sample disturbance is extremely demanded.

Many researchers utilized strength index devices for measuring the undrained shear strength for cohesive soils; Nearing [3] used Miniature vane, pocket penetrometer and fall cone devices as indicators for the effect of prestress on shear strength of clay, Leoni [4] adopted the Torvane and pocket penetrometer, for measuring shear strength of reconstituted soils, Vahdifard et al [5] used pocket pentrometer, pocket geotester and pocket vane shear for evaluating the strength changes of stabilized high water content soils, Howard and Badran [6] carried out a comparison study of hand held devices (Torvane and penetrometer) with the unconfined compression test for low strength cementitious material. The laboratory vane shear test was also adopted for measuring shear strength of remolded soil [7,8,9]. Velosa, et al [10] carried out an investigation on soft marine deposits using vane shear test and UU triaxial test on undisturbed samples. Li, et al [11] used different laboratory tests including Torvane, Miniature vane and UU traixial tests on calcareous marine clays. Ebrahimian et al [12] published results of geotechnical charactrization using laboratory tests including UU triaxial, Pocket penetrometer, Torevane and Miniature vane on recovered undisturbed samples from deep marine deposits.

The main objective of the present investigation is to demonstrate and discuss the potential of UU-triaxial testing to reasonably evaluate the undrained shear strength of soft marine soils, and to examine the capability of the simple strength index device such as the Miniature vane shear to comparably estimate the undrained shear strength of soft soils.

2. Soil samples

A total of 125 cores of marine soil recovered from shallow depths (0 to 6.0 meter) from sea bed of Benghazi offshore were available for conducting the laboratory investigation. The laboratory work consists of tests of soft marine soils, mainly for the evaluation of undrained shear strength by means of unconsolidated undrained triaxial test (UU) and the Miniature vane shear (MV).

Cores which reserved in 76 mm plastic tubes were cut to the required lengths either to be ready for extracting smaller samples for triaxial testing or to directly conduct the strength index testing without extraction from the reserved tube. Implementing the vane shear device MV is rapid and easy, it is not involving additional process of sample preparation as in triaxial test, hence avoiding extra disturbance. The test is directly made while sample remains inside sampling tube. For smaller size samples required for triaxial testing, extraction of 35 mm specimens were made according to the method described in ASTM - D3213 [13]. However, for such soft soils this method was not always successful since about 50 % of the prepared samples were exhibited high degree of disturbance and became insufficient for strength testing therefore they have been discarded from testing in the triaxial. Testing of soft soil is not an easy task, and therefore it requires extra care and special precautions in order to minimize sample disturbance. Samples extracted from tubes are prepared into suitable sizes so that the height to diameter ratio is equal or greater than two. Samples are handled very carefully in order to avoid distorting their original shape. Some samples especially those having high natural water content and which showed extra softening and hence, require extra care against bulging under its own weight are provided with some kind of support before placing it inside the rubber membrane and rapidly placed in the triaxial cell to minimize disturbance.

3. Basic soil properties

Soil classification tests including grain size analysis, Atterberg limits, physical properties such as water content, specific gravity, and bulk density and were determined for all samples from all depths. Other properties such as carbonate content was also obtained. The range of index and other basic properties are presented in Table 1. The void ratio of each sample was calculated by considering the samples are fully saturated and using the measured values of specific gravity and water content for the specified sample.

Table 1. Summary of the basic soil properties

Property	Minimum	Maximum	Mean
Liquid limit LL %	30.9	90.3	38.7
Plastic limit PL %	20.6	57.0	26.7
Plasticity index PI %	10.3	33.3	12.0
Water content Wc %	30.0	80.1	48.9
Specific gravity GS	2.4	2.8	2.6
Bulk density γ_b (Mg/m3)	1.6	2.3	1.9
Void ratio e	0.8	2.7	1.3
Fine fraction Fr %	25.9	98.5	82.9
Carbonate content CO3 %	29	93.5	59.5

The results are shown plotted in the soil plasticity chart in Fig. 1, the majority of the points are located below A-line, and according to Unified Soil Classification System (USCS), the soil is mostly classified as low plasticity silt (ML) or clay (CL) although some samples are of high plasticity (CH, MH), they were excluded from the testing program. The soil is containing large amount of fine material of an average of 83 %.the majority are of silt fraction. The average value of liquid limit is 39 % and only few samples show relatively high liquid limit, the plasticity index in most cases is not having a wide range.

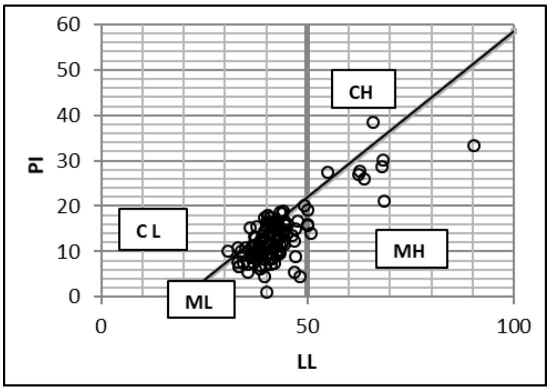


Fig. 1. Distribution of soil plasticity results within the Plasticity chart

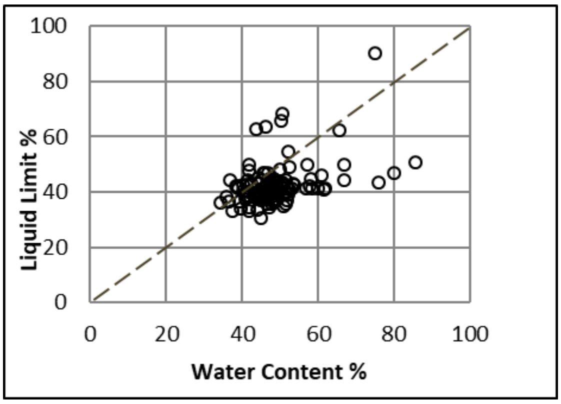


Fig. 2. Water content vs Liquid Limit

The natural water content is generally high with an average of 49 %, it is in most of the samples exceeding the Liquid limit as shown in Fig.2.

The average values of Atterberg limits and water content at each depth are plotted against sample depth in Fig.3, It can be seen that at all depths the water content is generally higher than the liquid limit.

Several consolidation tests on undisturbed samples taken from different depths were conducted using conventional Oedometer procedure in order to determine the over consolidation ratio by adopting the Casagrandi method, the results in Fig. 4 indicate that the soil is lightly over consolidated with OCR between 2-4 at shallow depths less than 2.5 m , reduced to approximately 1.3 at larger depths.

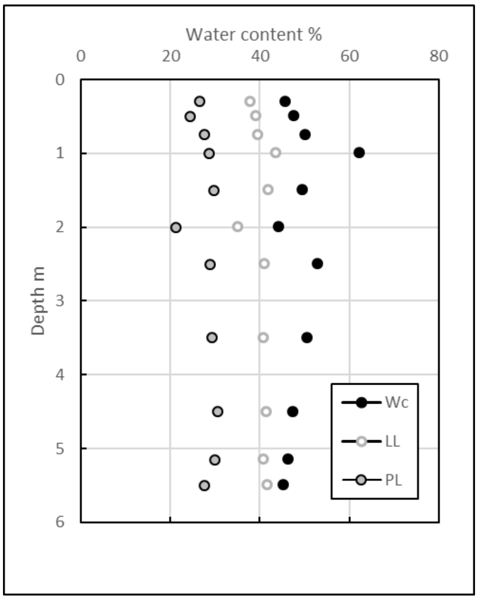


Fig. 3. Variation of water content and Atterberg limits with depth

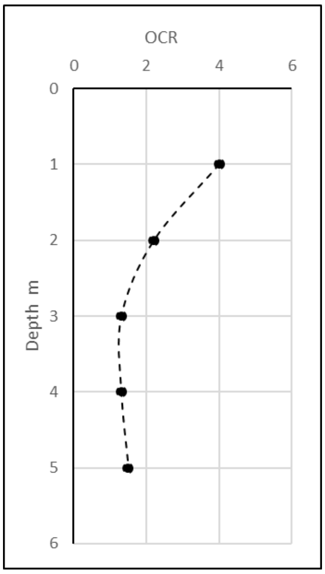


Fig. 4. Variation of OCR with depth

4. Strength testing method

4.1. Triaxial Tests

Directly upon placing the specimen inside the cell, it is immediately filled with water in order to allow some hydrostatic pressure to help maintaining specimen from becoming flabby. For samples recovered from shallow depths usually subjected to cell pressures higher than the corresponding value encountered in the field and generally not less than 50 kPa in order to provide enough confinement and prevent specimen from buckling during shearing stage. Samples were tested in a strain controlled triaxial apparatus shown Fig. 5a at a constant rate of 0.60 mm/min under unconsolidated undrained test condition. During testing the resulting force and displacement were recorded at small intervals in order to obtain smooth stress strain relationship. Because of initial soft condition of samples most samples were exhibiting high axial strain which led to noticeable sample bulging, and the majority of samples were not showing a clear failure plane (Fig. 5b). However, when deviator stress is maintaining constant value, the test usually terminated at nearly 15 % strain.

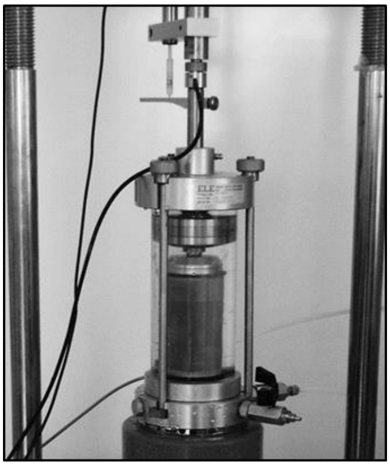
4.2. Miniature vane shear test

The set up for a Miniature vane shear test, is shown in Fig. 5c and the testing procedure followed is according to ASTM - D4648 [14]. The recorded strength is taken as the average of at least 3 measuring trials for each sample.

Measurement by the shear vane device was utilized for measuring both undisturbed and remolded shear strength. The undisturbed shear strength is measured by pushing the vane blades into the sample to at least twice its height and then rotate at a constant rotation speed and record the maximum equivalent torque. The remolded strength value is obtained by rewinding the vane back to its initial position before measuring undisturbed strength and rotate again for the second measurement, hence the new reading of maximum equivalent torque is recorded. However, what is arbitrary called here a remolded shear strength measured this way is rather the mobilized residual shear along a pre-sheared surface since the sample original structure was not completely destroyed by remixing.

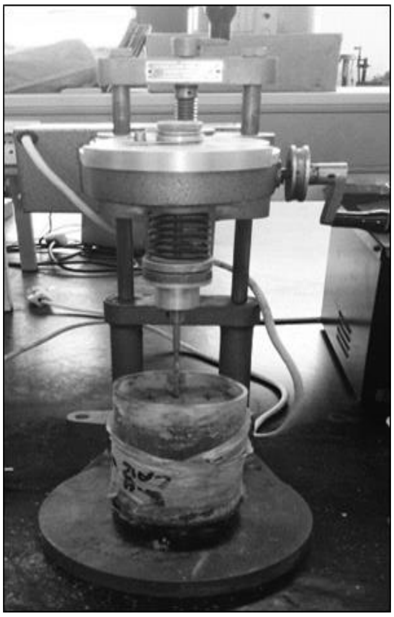
5. Results and Discussions

Attempts were made to test a total of (125) samples for the laboratory evaluation of undrained shear strength, only (59) samples were managed to be successfully tested in the UU-triaxial test and (84) in the (MV) apparatus. Table 2 contains a summary of the results of undrained shear strength obtained during testing of undisturbed samples in the triaxial apparatus and both undisturbed and remolded samples in the miniature vane shear device.



a) Triaxial test cell and sample.

b) Typical sample after testing in Triaxial



c) Vane shear test device and sample

Fig. 5. Testing samples and apparatus

Table 2. Summary of undrained shear strength results (kPa).

Test	Miniature vane shear (MV) undisturbed	Miniature vane shear (MV) remolded	UU-triaxial
Minimum	6.9	3,9	5.0
Maximum	39.1	24.1	28.0
Mean	14.8	10.0	11.6
Standard Deviation.	7.0	4.3	5.3

5.1. Undrained shear strength measured in triaxial test (UU)

The resulting undrained shear strength (Su) values obtained during triaxial testing are plotted against the vertical effective vertical pressure and presented in Fig. 6. The average undrained shear strength is 11.6 kPa and of a maximum value is not exceeding 28 kPa. Despite, the scatter of the resulting Su which is seen at shallower depths less than 2.5 m, with shear strength values above average, one can detect a slight tendency of increase of Su with depth especially at larger depths. Furthermore, Strength variability with depth may depend not only on the consolidation stresses (initially or mechanically induced), but also on the inherent variability of the soil layers [15]. Vipulanandan et al [16] analysed data collected from several places of soft marine soils around the world and suggested that, the trend of behaviour can be simulated by hyperbolic relationship between undrained shear strength (Su) and in-situ vertical stress (σv) with an ultimate value of Su = 25 kPa and a mean of 17.5 kPa. However, for the data in Fig.6 in which the resulting average of undrained shear strength obtained (Su=11.6kPa), is only 66 % of that mean value of soft soils. Bjerrum [1] evaluated methods to determine the undrained shear strength of soft clay soils and concluded that the laboratory triaxial tests on undisturbed samples consolidated to in-situ effective stress better represented the strength of the soft soil, hence UU test is obviously underestimated the undrained shear strength. The soil with such low shear strength thus categorized accordingly as a very soft soil. It could simply be affected even by low level of vibration or any means of mechanical process such as handling and cutting. It could also easily deform during preparation and trimming prior to testing. However, for soft material the occurrence of some kind of disturbance is generally unavoidable and subsequently scatter in resulting Su is expected.

Furthermore ,The scatter of Su at shallower depths shown in Fig. 6 may also be related to several factors such as the large variation of water content ,changes in soil plasticity as previously illustrated in Fig. 3 and also the possible existence of random distribution of local material constituent or variation in density , However the higher average values of Su recorded at shallow depths is attributed to the condition of previous stress history experienced by the soil being lightly over-consolidated within these levels. However, to account for effect of overconsolidation ratio OCR, the results again plotted as Su/OCR with the effective vertical stress and shown in Fig. 7, The relationship can be considered as linear with a slope of 0.28 which is slightly higher than that obtained by Misri [17] who suggested that the ratio between the undrained shear strength and pre-consolidation pressure is 0.22.

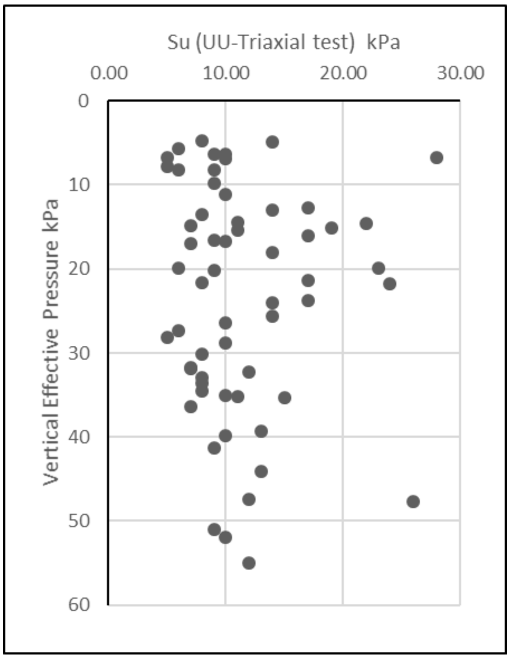


Fig. 6. Undrained shear strength vs vertical effective stress

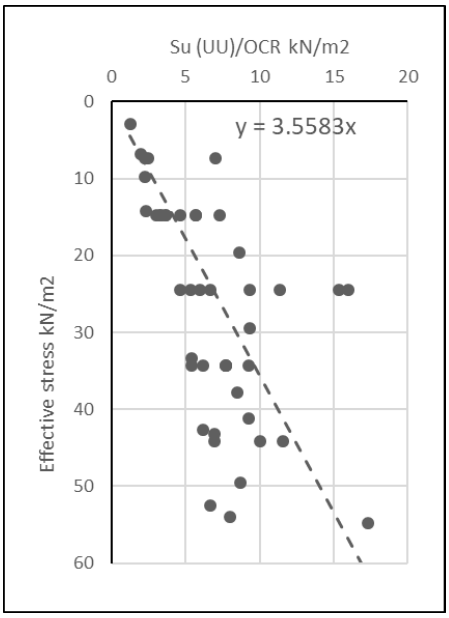


Fig. 7. Su (UU) vs vertical effective stress

5.2. Undrained shear strength measured by miniature vane shear test (MV)

I- Undisturbed shear strength

The results of undrained shear strength obtained using Miniature vane (MV) on undisturbed samples are plotted against sampling depth and shown in Fig. 8 together with UU-triaxial test results. The data in Table 2 indicated that the Su value evaluated by MV device is of an average of 14.8 kPa, it is generally 27 % higher than that obtained during traixial test, the maximum recorded value of Su is 39.1 kPa. The variation with depth is not maintaining any regular pattern and highly scattered in case of both UU and MV test results. Some researchers [12,18,11,10], related that to the effect of some sample disturbance.

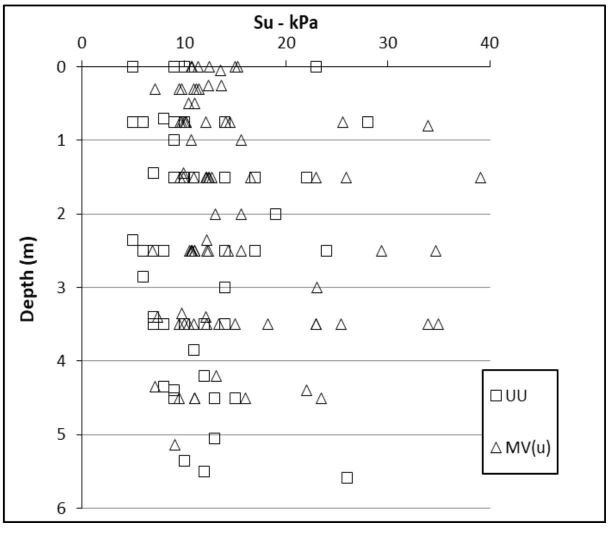


Fig. 8. Undrained shear strength vs depth measured by different devices

However, samples tested with MV device supposed to eventually exhibiting less disturbance, yet the large variability in the results was not reduced.

II- Remolded shear strength

The remolded shear strength measured by MV test device is with an average Su(r) of 10.0 kPa. The results are plotted against the undisturbed shear strength also obtained by MV device in Fig. 9. Good correlation can be seen from the results, the undisturbed strength is approximately 1.5 times the remolded value, nonetheless the soil is not showing high sensitivity upon remolding.

5.3. Comparison of measured strength

Referring to the results presented in Fig.8 the undrained strength Su measured by MV is generally higher than that obtained by Triaxial test (UU), As previously stated that the shear strength measured by MV were less affected by sample disturbance during testing. In fact, the variation in the measured undrained strength using deferent test methods is reported by several researchers [19,20], the different testing procedure involving different total stress path or deferent mode of shearing for undrained strength measurement is consequently produce deferent values of Su. Fig.10 presents plots of shear strength evaluated by UU against that obtained by MV test results for undisturbed samples,

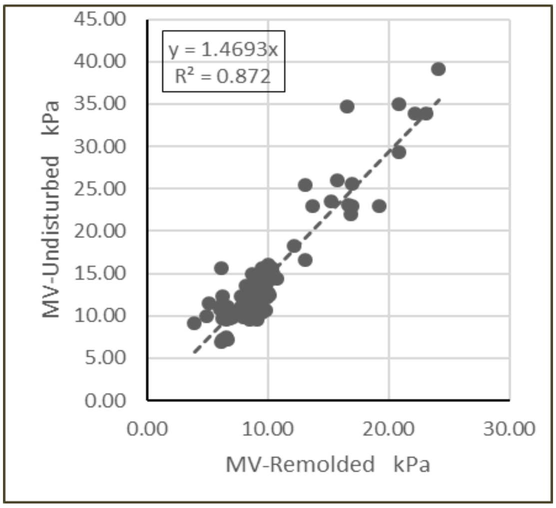


Fig. 9. Undisturbed strength vs remolded strength Using Miniature vane

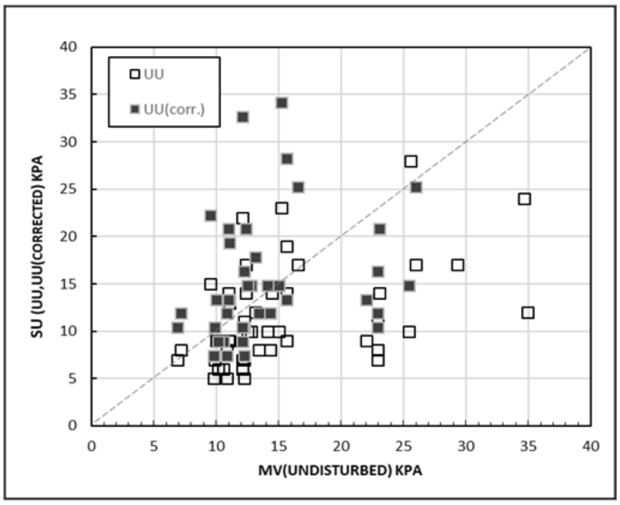


Fig. 10. Relation between results of Su from UU with Miniature vane

The shear strength values resulting from UU-triaxial test in Fig. 10 are generally lower than that obtained by MV device and as it was discussed earlier, the samples were very much affected by the process which preceded the testing and since during UU test, they have not been reconsolidated to their previous field effective pressure before testing. The reduction in measured Su in UU test compared with that measured by MV device is of the order of 27 %. The resultıng low undrained shear strength obtained here by triaxial testing is mainly attributed to extra disturbance during pre-test preparation process.

Two sources of sample disturbance may exist in this case, the first is due to the process of field sampling and the second occurs during sample preparation in the laboratory, however soils of water content equals or above liquid limit should not be considered totally undisturbed and some change in its original state is inevitable [21]. The redistribution of water content within the sample before testing is commencing may also be considered a cause of strength reduction [1]. Furthermore, testing soft material in undrained condition without reconsolidation of the samples to the corresponding field effective stress before shearing is also responsible for the resulting shear strength reduction.

As it has been stated earlier the average undrained shear strength obtained from UU test during this study is only 66 % of Su recommended by Vipulanandan et al [16] in his survey of undrained shear strength of soft marine soils around the world . Wroth [22] recommended the Su from isotropic consolidated undrained triaxial compression (CIUC) test as a standard test of reference for convenience in comparison of Su among various tests, Rataninikom et al [23] considered the resulting undrained shear strength from CIUC test as a reference to other test methods and hence, proposed some formulae to relate (Su) from different kind of testing method to that obtained during CIUC test, they express a relation with UU strength as given below;

$$(Su)_{uu} = 0.673\ (Su)_{cicu} \quad (1)$$

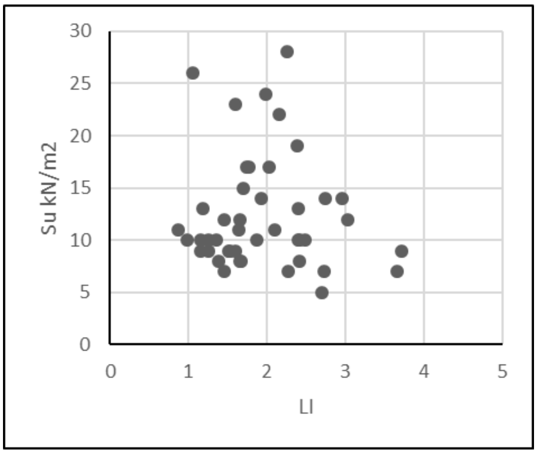
Where; $(Su)_{uu}$ is the undrained shear strength obtained by UU-triaxial test

and $(Su)_{cicu}$ is the undrained shear strength obtained by isotopically consolidated undrained triaxial test.

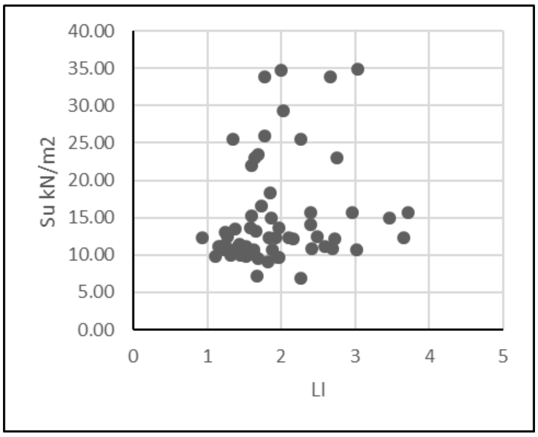
However, If Eq. (1) is used for correcting the shear strength values obtained by UU-triaxial test during the present investigation, the resulting undrained strength (UU)-corrected becomes reasonably comparable with MV test results as shown in Fig. 10.

5.4. Correlations with index properties

Many researchers realize that both undisturbed and remolded undrained shear strength of cohesive soils is significantly affected by the change of water content and therefore, suggested several correlations of undrained shear strength either directly with the water content (Wc), [24,4,9,16], plasticity index (PI) [25,26]; or liquidity index (LI), [21,27,28]. However, for the present work, since most of water content of tested samples are around liquid limit (LL) or above, with no wide range of Wc, it was found more convenient to relate the undrained shear strength with Liquidity index. since it is expressed in terms of the water content above plastic limit (PL) with respect to plasticity index PI, hence positive value indicates Wc higher than LL. The test results of Su obtained from various tests are plotted against LI and presented in figures (11a to 11b), The results are highly scattered with broadly similar pattern, there is some kind of aggregation of low Su values mostly within a range LI between 0.5 and 1.5. However, this is generally the case for the results of every test type and whether the tested material being undisturbed or remolded, It is inevitable however to accept such discrepancy when testing natural material having high water content, the resulting trend is broadly emulated with other findings for soft soils in the sense that shear strength inversely proportional to liquidity index. The results, therefore are arbitrarily correlated, despite the high degree of discrepancy.



a) Relation of Su from UU-Triaxial and LI



b) Relation of Su from Vane shear test (undisturbed) and LI

Fig. 11. Relation between results of Su from various tests with liquidity index

Bjerrum & Simons [28] showed that, for normally consolidated sensitive clays, the undrained shear strength ratio from triaxial compression test (CIUC) can be correlated with the plasticity index (PI) and liquidity index (LI), However for soft soils with relatively high water content the correlation with LI is more convenient. Furthermore, the tested soil in this work is of very limited range PI. The equation proposed by Bjerrum and Simons [28] and also adopted by Rataninikom et al [23] is given below;

$$(Su/\sigma_{vo}')_{CIUC} = 0.18/LI^{0.5}\ OCR^{m} \quad \text{(LI in decimal)} \quad (2)$$

Where $(Su/\ \sigma_{vo}')$ is the normalized undrained strength ratio and σ_{vo}' is the effective overburden pressure. OCR is taken as 1.3 for normally consolidated soil and m = 0.8.

Some researchers suggested that the relation is better expressed in terms of the normalized undrained strength $Su/_{\sigma p}$\` [17], and emphasized on the consideration of $\sigma_p$\` on developing a correlation of Su with index soil properties for low over-consolidation clay [29]. However, since the samples taken from shallow depths are lightly over consolidated, the test results can be better normalized with the average pre-consolidation σ_p\` considering average OCR=2.0 and m=0.8, therefore, Eq. (2) can slightly be modified so that;

$$(Su/\ \sigma_p')_{CIUC} = 0.45/LI^{0.75}\ OCR^{m} \quad (3)$$

The results are plotted in Fig. 12, the scatter still high but it demonstrates better correlation of the data with Eq. (3) after considering the soil as lightly over-consolidated with average OCR=2.0.

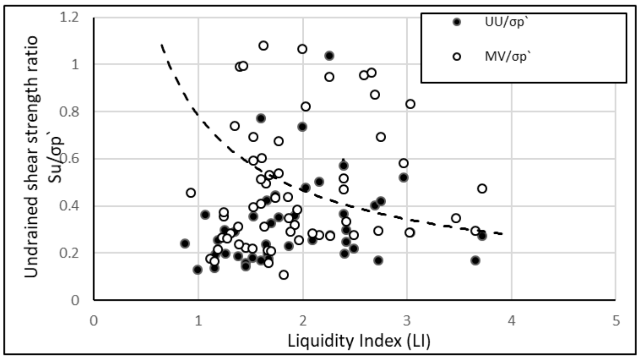


Fig. 12. (Su/σp') vs Liquidity Index

6. Conclusion

A series of laboratory tests were carried out on soft marine deposit utilizing two methods of testing UU-triaxial and Miniature vane shear (MV) tests. The following are the main conclusions;

Testing soft soils of high water content equals to liquid limit or higher is generally a difficult matter, therefore the use of unconsolidated undrained triaxial test to determine the undrained shear strength is only possible by providing extra care during sample preparation and testing stages. It is admitted that certain degree of sample disturbance could not be avoided.

The adopting of a simple strength index device such as Miniature vane to evaluate the undrained shear strength and reducing sample disturbance is considered an effective method and a reasonable alternative. In the present work the shear vane device was able to predict the undrained shear strength of about 27% higher than that obtained by UU-triaxial.

Attempt to relate the undrained shear strength with Liquidity index LI was only arbitrarily made possible despite of high scatter of the data it is generally comparable just with the trend reported by other research workers. The relation between undrained shear strength ratio (Su/σ_p') and LI was found better represented by the equation suggested by Bjerrum and Simons (1960) with some modification and consideration of the effect of over-consolidation ratio.

Acknowledgements

The authors wish to thank the Libyan Technical Consultancy (LTC) for their support and making the laboratory test data available.

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Quality Improvement in Investment Castings Using Genetic Algorithm

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Received: 17.05.2021 Accepted: 02.11.2021

Abstract- Investment casting is well-known for its distinguished characteristics such as manufacturing small industrial components of ferrous as well as nonferrous alloys used in aerospace, automobile, bio-medical, chemical, defense, etc. with closed tolerances at relatively low cost. These industrial components need to be defect free as well as must possess desired mechanical properties. This quality metrics (defect free castings with desired mechanical properties) is mainly driven by process parameters associated with different sub-processes of investment casting including wax pattern making, shell making, dewaxing, melting & pouring, and chemical composition of alloys. It is always challenging to identify such parameters affecting quality of investment castings. In this work, an application of Genetic Algorithm has been extended to identify critical parameters and their specific set of values affecting quality of investment castings. This technique is found be very useful in performing data analytics.

Keywords: Investment Casting, Data Analytics, linear Regression, Genetic Algorithm.

1. Introduction

Investment casting is mostly employed to product industrial castings used in aerospace, automobile, bio-medical, chemical and defense sectors [16]. It is mainly comprised of various sub-processes including wax pattern making, shell making, dewaxing, and melting & pouring. Wax patterns are usually prepared by using 30-70% industrial wax, 20-60% plastic, and 0-5% resin. The industrial wax is usually kept in molten state using heater fitted in wax injection machine, and injected into metallic die (usually made of aluminum) to make pattern (replica of casting). These patterns initially cleaned, and then assembled with gating system (sprue, runner as well as gate) to form the tree (assembly of number of wax patterns forming tree like shape). This assembled tree is progressively dipped into ceramic slurry (mixture of zircon flour, binder such as colloidal silica, and some additives) to form coating surrounded to it. The shell (mold) is cured in controlled environmental condition to achieved desired strength. The shell (once cured) is then passed through dewaxing process where wax is ejected (mostly through autoclave machine), and sent for preheating (usually for 30-45 minute at 1000-1100^{0}C) to improve hot strength. Metal/alloy is melted in furnace, and then molten metal/alloys is poured into heated shell. Shell is broken (once it is cooled) to get castings [1][2].

Investment casting mostly faces quality issue related to occurrence of defects including flash (excess metal dropping perpendicularly on the surfaces), misrun (cavities void of liquid metal in the mold), ceramic inclusion (trapping the particles of the ceramic on the surface or subsurface of castings), slag inclusion (dropping off a combination of metal and investment materials on the surface of castings), shrinkage (tiny cavities similar to a sponge in the last solidifying portion), sweating (dropping metal irregularly on the surfaces of castings), distortion (regarding the shape in original for castings), and crack (The local discontinuity is formed from concentrated stress through solidification). The castings also possess higher set of mechanical properties such as ultimate tensile strength, yield strength, and elongation [1][2].

The quality metrics mentioned above is highly influenced by process parameters as well as chemical composition of alloys. These parameters are also varied in various sets. It is pressing need to identify such parameters and their specific set of values to achieve desired quality in investment castings. Once these parameters are identified, it becomes relatively easy to control form improving the quality in castings [1][2].

In this work, relatively new approach, genetic algorithm is employed to identify such parameters and their specific set of values from data set collected from an industrial foundry located at authors' home town. It really provided an opportunity to explore genetic algorithm for identifying such parameters, and found it very useful in implementation.

2. Literature Review

Various researchers have attempted to explore Genetic Algorithm (GA) for optimization of process parameters for various processes. Patel et al, (2016) applied GA to determine the optimal process parameters. Model has been develop using nonlinear regression to recognize the considerable impact of the process parameters of the squeeze cast method on surface hardness, tensile strength, and roughness. Santos et al, (2003) developed a computational algorithm for the continuous casting method to maximize quality of steel billet. The GA has been integrated with a mathematical model using knowledge base of operational parameters. Anijdan et al, (2006) developed a theoretical model based on GA that was further integrated with artificial neural network to optimize the parameters responsible for the formation of porosity in castings of Al-Si alloys. Ducic et al, (2017) exhibited an application of GA for sand casting process to optimize the geometry of the gating system for maximizing the filling rate. Vijian et al, (2007) developed a mathematical model using multivariate linear regression analyses to formulate the objective functions that can further be used in development of GA for optimizing squeeze casting process parameters to improve mechanical properties of castings. Patel et al, (2016) used three evolution algorithms including Particle Swarm Optimization, Genetic Algorithm, and Multi Objective Particle Swarm Optimization Algorithm using Crowding Distance technique (MOPSO-CD) for improving the variables related to input-output in squeeze casting process. It was observed that these techniques can be implemented for optimization of variables in casting process however GA performs better in comparison with other approaches. Tsoukalas (2008) developed an efficient approach using multivariable linear regression with the GA to reduce the porosity in Al alloy manufactured using die casting process. The application of GA with multivariable linear regression is found to be very effective for improving the performance of process. Lagdive et al, (2013) used the GA with computer-aided design to generates an intelligent initial design for riser, and found it very useful in getting improved results.

It was revealed that several researchers have explored the application of GA in optimizing the overall performance of casting process with relatively small number of parameters. However, an application of GA for investment casting process where relatively large number of parameters are varied in wide set is not fully explored. As GA mainly relies on information related to input data as well as output, large set of input was collected from an industrial investment casting foundry located in Rajkot (India). Detailed methodology adopted for identification of critical parameters and their specific set of values affecting quality of investment casting is discussed next followed by results and discussion on it.

3. Methodology

Methodology adopted for identification of critical parameters and specific set of values affecting quality of investment casting is shown in Fig. 1.

Pre-processing section mainly focused on collection of data from industrial foundry, and development of relevant model using linear regression. The developed model will further be utilized for applying GA. Processing performs analysis using GA that further includes different steps such as initialization as well as selection of population, followed by reproduction and termination of population for converging the solution. Post-processing provides results related to critical parameters and their specific set of values to achieve desired quality through model developed by GA. Detailed explanation of each step is given next.

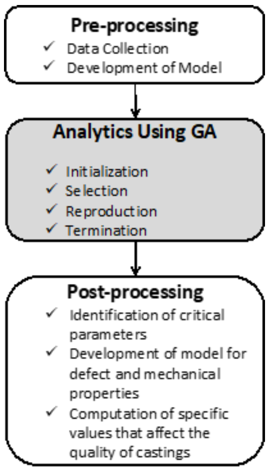

Fig. 1. *Methodology adopted*

4. Pre-processing

Input data related to process parameters as well as chemical composition and quality metrics (occurrence of defects as well as mechanical properties) was collected from an industrial investment casting foundry located at Rajkot (India). In total, 15 parameters related to process parameters; 9 parameters related to chemical composition; five defects such as slag inclusion, shrinkage, misrun, flash and ceramic inclusion; three mechanical properties (UTS, YS and ELOG) were collected, and stored in the form of spreadsheet. Occurrence of defects was entered "1" while non-occurrence of defects as "0". However, data related to shell weight before as well as after dewaxing was further merged together to get its absolute value (initial weight was subtracted from its final weight). The input data collected was related to nearly 360 heats (cycle of melting and pouring) of industrial casting (Fig.2) that has major application in automobile sector. Input parameters along with minimum and maximum values of each parameters as well as values of mechanical properties are shown in Table 1.

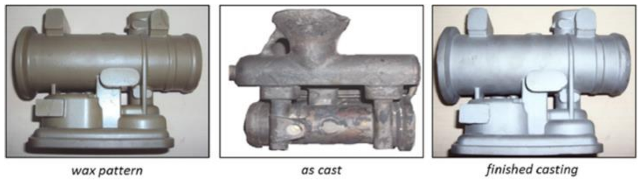

Fig. 2. *Industrial castings*

These parameters are further utilized for development of model that will further be utilized in performing analytics using GA. Model was developed using fundamentals of multiple linear regression shown in equation 1.

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \cdots + \beta_p x_{pi} + e_i \ldots(1)$$

where: β_0: is the constant, *P:* number of variables and each variable has its β coefficient.

5. Analytics Using GA

Genetic Algorithm is a computational technique that provides exact or approximate solutions especially for optimization as well as search related problems, and categorized as one of the evolutionary algorithms [3]. Detailed discussion on methodology to optimize the problem using GA is available in various literatures [3][6][7][8][9][12]. GA is usually employed to evolve the expressions (equations) for optimizing the process where number of variables are (similar to number of variables in investment casting process) relatively large (say, 10,20 50 or more) [3]. The GA usually adopts steps initiate for an initial population from input data; select most possible solutions through evaluation using

Table 1. *Details of input and output parameters*

Input/Output	Notation	Units	Minimum	Maximum	Mean
Input – Process Parameters					
Metal Preparation Time	x_1	min	55	135	75.78
Tapping Temperature	x_2	^{0}C	1550	1580	1559.60
Injection Time	x_3	sec	0.83	10.4	8.83
Press Room Temperature	x_4	^{0}C	18	21.67	18.60
Press Room Humidity	x_5	%	69.75	90	78.43
Duration of Process	x_6	In days	2	7	4.32
Weight of Shell (difference between weight of shell after dewaxing and before dewaxing)	x_7	kg	1.34	2.64	1.89
Slurry Viscosity - Primary	x_8	sec	20.38	23.59	21.54
Slurry pH - Primary	x_9	--	9.0	9.50	9.35
Temperature of Coating Room - Primary	x_{10}	^{0}C	19.25	24.33	21.90
Humidity of Coating Room - Primary	x_{11}	%	9.50	79.7	68.72

Slurry Viscosity - Secondary	x_{12}	sec	10.32	11.06	10.56
Temperature of Coating Room - Secondary	x_{13}	^{0}C	20.5	26.4	23.41
Humidity of Coating Room - Secondary	x_{14}	%	64.75	85.40	75.20
Input – Chemical Composition					
Nickel-Extra	x_{15}	**%**	0.001	0.66	0.08
Manganese	x_{16}	**%**	0.751	1.26	0.96
Carbon	x_{17}	**%**	0.04	0.07	0.05
Silicon	x_{18}	**%**	1.12	1.37	1.23
Phosphorous	x_{19}	**%**	0.03	0.04	0.037
Sulphur	x_{20}	**%**	0.01	0.03	0.01
Nickel	x_{21}	**%**	8.01	8.46	8.18
Chromium	x_{22}	**%**	18.02	18.54	18.27
Molybdenum	x_{23}	**%**	0.11	0.31	0.23
Output – Mechanical Properties					
Ultimate Tensile Strength	y_1	MPa	506.10	588.40	556.65
Yield Strength	y_2	MPa	220.50	305.10	282.31
Elongation	y_3	%	50.20	60.40	55.50
Output – Defects					
Ceramic Inclusion	y_4	--	--	--	--
Flash	y_5	--	--	--	--
Misrun	y_6	--	--	--	--
Shrinkage	y_7	--	--	--	--
Slag Inclusion	y_8	--	--	--	--

fitness function; reproduce the results; terminate the process based on desired criteria to get optimized results. Various steps to be followed for analytics using GA is shown in Fig. 3.

5.1 Initialization

This is the first step for optimization of process using GA, and it generates (randomly) many individual solutions from input data. This usually generates all possible solutions, and evaluation criteria needs to be provided for selecting most optimum solution suitable for relevant process. As discussed earlier, data collected from an industrial investment casting foundry is stored in the form of spreadsheet, and used for initialization of solution. This step has generated all possible solutions using input data, and will forward the possible solutions for selection (shortlist).

5.2 Selection

This is one of the very critical steps in optimizing process using GA. This step selects few solutions among all possible solutions (generated in the initialization step). The selection is carried out using fitness-based process using *fitness function* that will select appropriate fitter solution for next step. Selection of appropriate method for selecting possible solution among all possible solutions is very critical as inappropriate selection may take very long time for getting solution or solution may not be converged for final solution. The selected solutions will further used in reproduction step that will generate second generation (mutation) of possible solutions from it.

5.2.1.1 Reproduction

This step will generate second generation of populations from shortlisted solutions from previous step. This is achieved by selecting a pair (usually known as *parent*) of solutions from the selected possible solutions. This is followed by crossover and mutation process among parent for creating next level of solution (known as *child*). This next level of solution (*child*) usually have many characteristics from its *parent*. The process of reproduction continues till new set of possible solutions is generated. This in turn leads into generation of entirely new set of solutions that was achieved at the end of initialization step as *fitness function* selected the best possible solutions from the results of previous steps. The reproduction process is continuous process, and it has to be terminated to achieve desired solution that fulfils predefined criteria.

5.2.1.2 Termination

The reproduction was continued till either of following termination criteria was achieved. Most common termination criterion used in termination of reproduction step is either of followings [3]:

- Number of generations (i.e. iterations),
- Time taken for achieving solution,
- Highest fitness achieved beyond which improvement in results is not possible,
- Manual inspection of results for observing improvement in results.

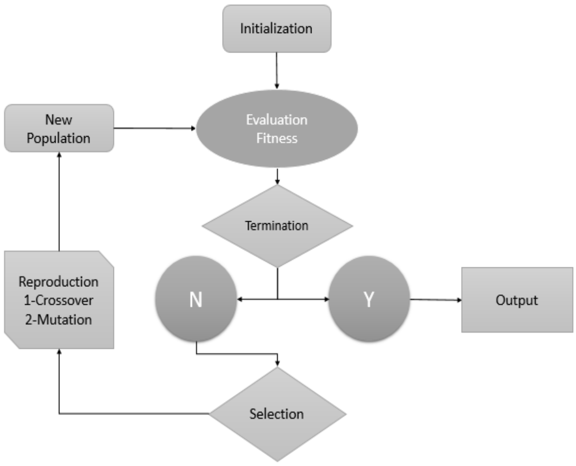

Fig. 3. *Overview of analytics carried out using GA*

As discussed earlier, input data related to 358 heats comprising 15 process parameters, 9 chemical composition of alloy, five defects and three mechanical properties was used to as an input to identify critical parameters and their specific set of values to achieve desired quality in investment castings using GA. This data was used to generate multiple linear equations that will be used in selection step for analytics using GA. Generalized equation was generated (equation 2), and their relevant coefficients for data related to defects and mechanical properties are shown in Table 2.

$y_{di} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_{23} x_{23}$……(2)

where y_i= outputs; y_1= Ultimate Tensile Strength; y_2= Yield Strength; y_3= Elongation, y_4= Slag Inclusion; y_5= Shrinkage, y_6= Misrun; y_7=Flash; y_8= Ceramic Inclusion; β_0 = Intercept; $x_{1,2,3....23}$ = Process parameters and chemical compositions; $\beta_{1,2,3...23}$= Relevant co-efficient of process parameters and chemical compositions

In total, 358 solutions were possible for optimization after passing through selection step. These solutions were further passed through *fitness function*. Two different sets of fitness function were employed each for separate set of outputs (mechanical properties and defects). Fitness function related to defects were modeled in such way that yield in minimization of defects while for mechanical properties that yield in maximization.

Table 2. *Values of the Coefficients – Mechanical Properties and Defects*

	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8
β_0	0.6323	0.8502	0.9733	0.32	-0.0718	0.0769	0.8426	0.8501
β_1	-0.056	-0.053	0.069	-0.01	0.082	0.041	-0.2	-0.18
β_2	-0.045	-0.025	-0.29	0.16	0.054	0.039	-0.19	-0.18
β_3	-0.0022	-0.032	-0.15	-0.018	0.12	-0.046	-0.019	0.0054
β_4	0.064	0.056	0.052	0.037	0.12	0.049	-0.21	-0.33
β_5	0.11	0.037	0.051	-0.13	-0.0049	0.041	-0.27	-0.39
β_6	0.17	-012	0.08	0.031	-0.031	-0.039	0.34	0.25
β_7	-0.34	0.064	-0.36	-0.1	-0.043	0.073	-0.47	-0.49
β_8	-0.15	-0.027	0.024	0.032	0.11	0.22	0.04	-0.032
β_9	-0.034	0.027	-0.046	0.06	0.1	0.078	-0.095	-0.14
β_{10}	-0.069	0.077	0.044	0.39	-0.086	0.35	0.15	0.1
β_{11}	0.11	-0.12	0.092	-0.12	0.032	-0.14	0.1	0.13
β_{12}	0.04	-0.0013	0.13	-0.083	-0.046	-0.17	0.029	0.07
β_{13}	0.036	-0.066	0.068	0.018	-0.17	-0.15	-0.013	-0.066
β_{14}	-0.007	0.079	0.0032	0.18	0.12	+0.19	0.15	0.12
β_{15}	-0.28	0.11	-0.31	0.11	0.096	-0.16	-0.25	-0.13
β_{16}	0.1	-0.012	-0.098	-0.17	-0.062	-0.055	-0.17	0.0022
β_{17}	0.12	0.069	0.11	-0.14	0.19	-0.035	-0.026	-0.065
β_{18}	-0.082	-0.066	0.11	0.065	-0.19	-0.11	-0.059	-0.043
β_{19}	-0.13	-0.2	-0.28	0.14	0.16	-0.032	0.2	0.071
β_{20}	-0.033	0.015	-0.44	-0.17	-0.13	-0.024	-0.0086	0.16

β_{21}	0.038	0.0017	0.17	-0.11	0.098	0.033	-0.12	-0.21
β_{22}	-0.25	-0.051	-0.096	-0.014	-0.051	-0.17	-0.048	-0.016
β_{23}	0.1	0.037	-0.093	-0.24	0.079	-0.041	-0.13	-0.15

The fitness function was employed to evaluate each solution. In total, 150 solutions were further selected for reproduction. The reproduction was further iterated for 100 generations, and terminated as it was not showing further improvements in results. The solutions using GA was coded and executed on the platform of python.

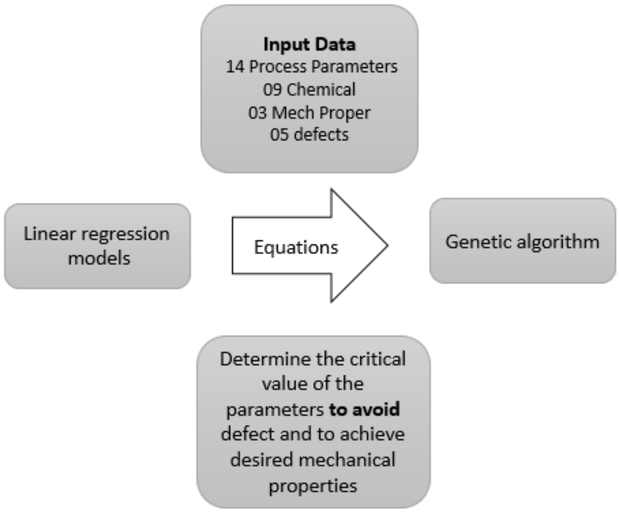

Fig. 4. *Computation of critical parameters*

6. Results

The input data related to process parameters, as well as chemical composition used to identify critical parameters and their specific set of value affecting the quality (minimizing the occurrence of defects and maximizing the mechanical properties) of investment castings using GA. The parameters and their specific set of values to achieve desired quality of investment castings are shown in table 3.

7. Discussion

The Genetic Algorithm based model has been successfully developed and found to be useful for identifying the specific set of values affecting the quality of investment castings. The models can be easily embedded with cloud based technology, and utilized by user. This model do not need a high level of domain knowledge or computation tools (as for simulation software). The process data can be collected from an industrial foundry and stored in spreadsheet, which can be formed the main input. The model was tested on real-life data obtained from an industrial investment casting foundry, and was found to be easy to use by foundry engineers, without any training or customizing. The parameters identified for achieving desired quality are considered to be in line with previous work. pH values of primary slurry and humidity of primary coating room drives the quality of the ceramic shell; affects heat transfer rate during solidification of alloy, and alter the mechanical properties. Similarly, weight of shell drives the thickness of coating. Thin shell improves the heat transfer between shell and alloy, and affects the mechanical properties of alloy. However, difficult to establish the complete correlation between parameters and quality of investment casting, and more research may be needed in this direction.

Table 3. Specific Set of Values Affecting Quality of Casting

Parameter	**Notation**	**Mechanical Properties**			**Defects**				
		y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8
Metal Preparation Time	x_1	69	75	70	65	66	70	73	115
Tapping Temperature	x_2	1558	1553	1557	1561	1558	1563	1568	1562
Injection Time	x_3	9.4	9.7	5.63	10.1	9.7	9.4	9.2	7.2
Press Room Temperature	x_4	18	19.9	21.7	18	18	19.32	18	18
Press Room Humidity	x_5	90	69.8	75.6	84.9	77	73.2	84.2	84.1
Duration of Process	x_6	7	4	4	3	4	4	3	4

Weight of Shell (difference between weight of shell after dewaxing and before dewaxing)	x_7	1.5	1.5	1.1	1.5	1.3	1.4	1.5	1.4
Slurry Viscosity - Primary	x_8	21	21.7	22.4	20.5	20.4	20.6	21.7	21.7
Slurry pH - Primary	x_9	9.3	9.5	9.3	9	9.5	9.25	9.5	9.5
Temperature of Coating Room - Primary	x_{10}	21.6	21.8	23.7	21.2	23	23.1	22.2	21.7
Humidity of Coating Room - Primary	x_{11}	71.3	9.5	79.4	73.4	67.1	69.9	9.5	9.5
Slurry Viscosity - Secondary	x_{12}	11.1	10.6	11.1	10.4	10.5	10.4	10.5	10.5
Temperature of Coating Room - Secondary	x_{13}	21.8	22.8	21.8	23	26.4	25.9	26.4	25
Humidity of Coating Room - Secondary	x_{14}	82	20.4	82	73.6	76.5	79.6	76.4	69.5
Nickel-Extra	x_{15}	0.05	0.24	0.09	0.001	0.07	0.1	0.7	0.1
Manganese	x_{16}	0.82	1.27	0.85	0.85	1.07	0.93	1.03	1.02
Carbon	x_{17}	0.06	0.04	0.06	0.05	0.05	0.06	0.05	0.05
Silicon	x_{18}	1.23	1.32	1.2	1.25	1.25	1.28	1.2	1.2
Phosphorous	x_{19}	0.03	0.03	0.03	0.037	0.037	0.037	0.038	0.039
Sulphur	x_{20}	0.01	0.01	0.01	0.008	0.008	0.01	0.008	0.009
Nickel	x_{21}	8.01	8.06	8.27	8.17	8.13	8.19	8.20	8.26
Chromium	x_{22}	18.14	18.14	18.25	18.096	18.28	18.05	18.36	18.48
Molybdenum	x_{23}	0.24	0.20	0.23	0.25	0.21	0.26	0.24	0.28

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INTERNATIONAL JOURNAL OF ENGINEERING TECHNOLOGIES-IJET

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Conferences

[3] Çolak I., Kabalci E., Bayindir R., and Sagiroglu S, “The design and analysis of a 5-level cascaded voltage source inverter with low THD”, *2nd PowerEng Conference*, Lisbon, pp. 575-580, 18-20 March 2009.

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References

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