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Evaluation of existing concrete shear walls of building to resist new lateral loads

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تقييم حوائط قص خرسانية لمبنى قائم لتحمل أحمال جانبية جديدة

الطويل زايد الطويل
قسم الهندسة المدنية ، كلية التقنية للعلوم التطبيقية، العواته، ليبيا

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Abstract:
The main aim of this paper is to evaluate the behaviour of existing Reinforced concrete shear walls to resist new lateral loads which will may applied from an additional steel space frame which suggested by architectural designer, study of concrete stair case and elevator walls of building as support of large value of lateral reaction of space frame, the concrete walls investigated under concrete compression strength, lateral displacements due to new lateral loads, and chemical tests. Results show that concrete compression strength of these concrete walls is generally weak, about 50 % of required strength, calculated lateral displacement is large, and sulphate contents exceeds normal value with 18 %, sulfur trioxide exceeds normal value with 5 %, chloride is significantly low, total dissolved soluble exceeds normal value with 220 %, hydrogen ions are high and exceeds normal value with 57 %, carbonation is very deep and exceeds concrete cover with 22 mm. So these walls are considered not able to resist new lateral loads safely, the author suggested to design steel space frame supporting itself or new proposal of an architectural view of building, on the other hand repair of these concrete walls should be done.

Keywords : Behavior of concrete walls, lateral loading, space frame, chemical components Of existing concrete.

الملخص:
إن الهدف الرئيسي من هذا البحث هو تقييم سلوك حوائط قص خرسانية قائمة لتحمل أحمال جانبية جديدة التي ممكن أن تطبق على الحوائط الخرسانية من ناتج إسناد هيكل فضائي فولاذي عليها و الذي رغب المصمم المعماري إضافته للمبنى, تم دراسة الحوائط الخرسانية لسلالم و مصاعد مبنى قائم لتكون ركائز لحمل جانبي جديد ناتج من ردود أفعال بقيمة كبيرة لهيكل فضائي, الحوائط الخرسانية تم تقييمها تحت مقاومة الضغط, و الإزاحة الجانبية التي ممكن أن تحدث لها جراء تطبيق الأحمال الجانبية الجديدة, و المركبات الكيميائية داخلها, النتائج توضح بأن مقاومة الضغط لهذه الحوائط ضعيفة جداً بشكل عام , و هي اقل من المقاومة المطلوبة بـ 50 % , و الازاحة الجانبية المحسوبة من الحمل الجانبي الجديد عالية جداً, و محتوى الكبريتات عالي و يزيد عن الحد المسموح به بـ 18 % , و الكلوريدات متواجدة بنسبة قليلة, و مجموع الأملاح المذابة عالية جداً و تزيد عن المعدل الطبيعي بنسبة 220 %, أيونات الهيدروجين داخلها عالية و تزيد عن المعدل الطبيعي بـ 57 %, الكربونات داخلها عميقة و تزيد عن الغطاء الخرساني بـ 22 مم, و بالتالي أعتبرت الحوائط الخرسانية القائمة غير قادرة على تحمل الأحمال الجانبية الجديدة, و لذا إقترح الباحث تصميم الهيكل الفضائي حاملاً لنفسه أو إقتراح واجهات معمارية جديدة للمبنى, و من ناحية أخرى عدم إهمال إصلاح و تأهيل الحوائط الخرسانية القائمة.

الكلمات المفتاحية: سلوك الحوائط الخرسانية, التحميل الجانبي, الهيكل الفضائي, المركبات الكيميائية للخرسانية القائمة.

1. Introduction

Through the importance of safety of existing concrete shear walls of building which to be used as management building, the building is located in Tripoli, near university of Tripoli, opposite of Tripoli medical centre, about 6.7 km from the coast, the building has checked by designer through safety of elements due to structure analysis, and safety of foundations but not through safety of shear walls under new lateral loads, so check of concrete shear walls safety through

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calculation and tests became very important, specially some walls noted with corrosion and damage. The building is constructed in 1980 and used as mall, except sixth floor is constructed recently based on designer decision, the building with new view will be used as office building. Through the wish of an architectural designer who decided to add steel space frames covered with glass fiber Reinforced concrete (GRC) as new view of building as shown in figure (1), the space frames have a width of 31 m, a length of 53 m, and a height of 45 m, these steel space frames will be laterally supported with existing concrete walls as shown in figure (2).



Figure 1. Building's new view with space frame.

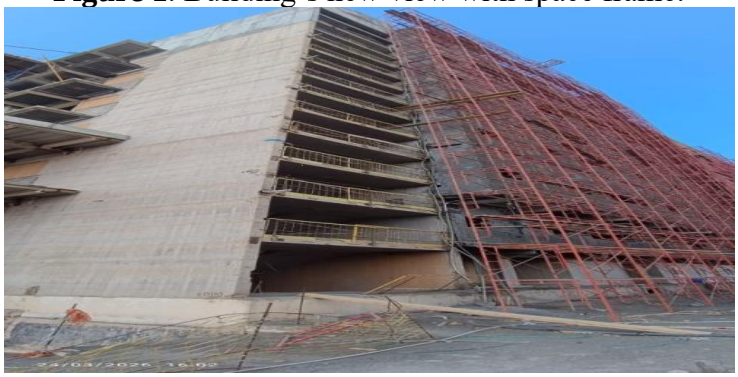


Figure 2 (a). Concrete shear walls as support of space frames (6th floor constructed recently).

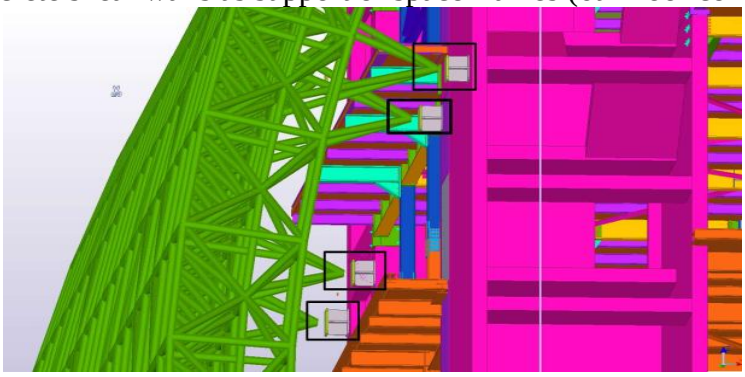


Figure 2 (b). Concrete shear walls as main lateral support of space frames.

Some of concrete shear walls noted with corrosion of steel reinforcement and concrete damage as shown in figure (3).



Figure 3. Damage and steel corrosion of Concrete walls.

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The existing concrete shear walls are eight as shown in figure (4), in addition of vertical support four are stair case walls (CW2, CW6, CW7 and CW8) which will be main lateral support of steel space frames with huge reaction value, and the other four concrete shear walls are elevator walls (CW1, CW3, CW4 and CW5) which will help to resist lateral displacement.

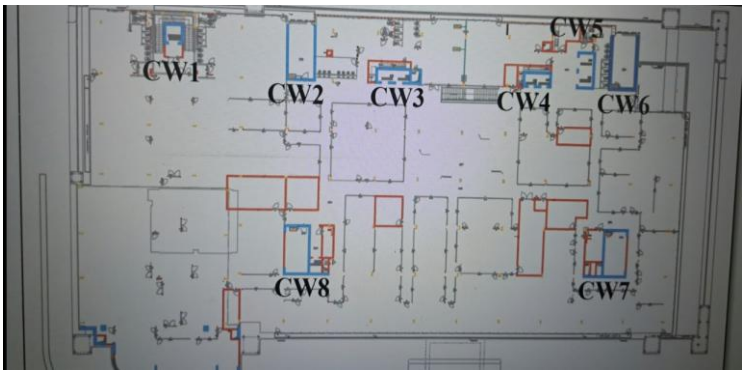


Figure 4. Lay-out of building with concrete shear walls.

All shear walls start from basement to roof above sixth floor except wall (CW1) which starts from basement to third floor. The detail of concrete shear walls is shown in table (1).
Based on structure Analysis done by designer, using design criteria shown in table (2) and ETABS for additional structure (space frame) as shown in figure (5) below, it supports on concrete shear walls at 16 points as shown in figure (6) with huge value of reactions as shown in table (3).

Table 1. Detail of existing concrete walls.

Concrete shear wall	Shape	Thickness in mm	Architectural function	Structural function In addition of vertical support
CW1	Box shape	300	Elevator wall	Lateral displacement
CW2	U shape	300	Stair case wall	Lateral support of space frame
CW3	Box shape	300	Elevator wall	Lateral displacement
CW4	Box shape	300	Elevator wall	Lateral displacement
CW5	Box shape	300	Elevator wall	Lateral displacement
CW6	U shape	300	Stair case wall	Lateral support of space frame
CW7	U shape	300	Stair case wall	Lateral support of space frame
CW8	U shape	300	Stair case wall	Lateral support of space frame

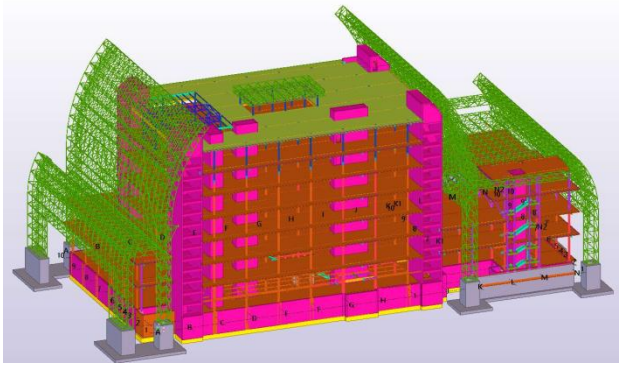


Figure 5. Existing structure with additional structure.

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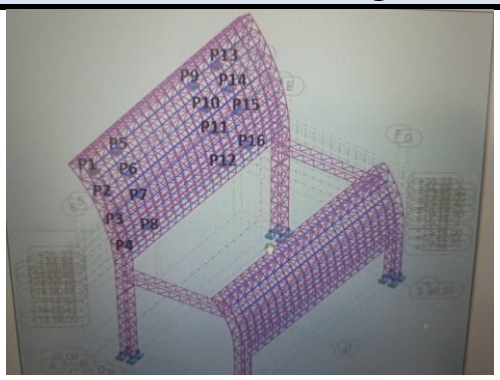


Figure 6. Supports points of new structure on existing concrete shear walls .

Table 2. Design criteria of space frame.

Load case	Magnitude kg/m^2
Self weight	30
Cladding load (GRC)	50
Live load	40
Wind load	132
Earthquake load	11
Temperature effects	+/- 30 Centigrade

Table 3. Maximum new reactions at existing supports.

Support	Magnitude kN	Support	Magnitude kN
P1	98	**P9**	387
P2	14	**P10**	48
P3	83	**P11**	205
P4	320	**P12**	631
P5	413	**P13**	358
P6	95	**P14**	77
P7	279	**P15**	296
P8	630	**P16**	698

The main objective of this research is to evaluate the strength of existing concrete shear walls to support the new additional structure (space frame) safely without any additional strength. Thus the strength of Reinforced concrete walls should be estimated based on an actual concrete compression strength, chemical test result, and calculated lateral desplacement. The new loads with huge reactions shown in table (3) may lead to failure of existing concrete shear walls. So a total of 8 Reinforced concrete shear walls investigated under compression core test, chemical tests, and calculated lateral displacement and compared to specification limits to decide if these walls are able to resist new lateral loads due to new architectural view of building.

Material and methods

The results reported in this paper were obtained from structure analysis of new frame using ETABS, and core test results to obtain concrete compression strength of existing concrete of shear walls, to compare an actual concrete strength with allowable stress limit of concrete according to ACI 318-19 [1], and to compare it also with concrete compression stress required by designer, and chemical tests including the following:-

- Percentage of Acid- soluble Sulphate content (SO4 %).
- Percentage of Sulfur trioxide (SO3 %).
- Percentage of water soluble chloride content (CL %).
- Total dissolved soluble (T.D.S) like (Calcium, Sodium, and mineral salts).
- And a measure of hydrogen ion (PH).
- Carbonation depth.

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To compare chemical results with an allowable limits according to NF P18-011 [2], and EN 206 [3]. The results reported in this paper was also obtained from calculated lateral displacement using structure analysis obtained from ETABS to compare it with maximum limits according to BS EN 1990-2023 [4].

Concrete cores

Concrete cores taken from all concrete shear walls which will support the new lateral load (CW2, CW6, CW7, and CW8) at each floor, and from some floors of other concrete shear walls which will assist to avoid lateral decplacement (CW1, CW3, CW4, and CW5). Concrete cores taken with dimension about 74 mm of diameter and about 146 mm of height, for compression test. Then concrete core were weighted and covered by caps to avoid stress concentration during compression test. And about 50 mm of diameter and about 100 mm of height, for chemical tests. The gap of taken samples from concrete walls then filled with grout of high compression strength.

All samples were then moved to Asakhra labratory (**ROTECH**) in Tripoli and tested.



Figure 7. Concrete core sampling from existing walls for compression and chemical tests.



Figure 8. Compression test of concrete cores after capping.

Results and discussion

Compression strength

Figure (9) illustrates the difference between required concrete strength by designer and actual concrete compression strength recorded in laboratory during concrete cylindre crash in Mega Pascal (MPa) of concrete walls (CW2,CW6,CW7,and CW8) which considered as main support of new lateral loads. Results show that concrete strength of main walls is very weak. The difference various from 11 to 14 MPa.

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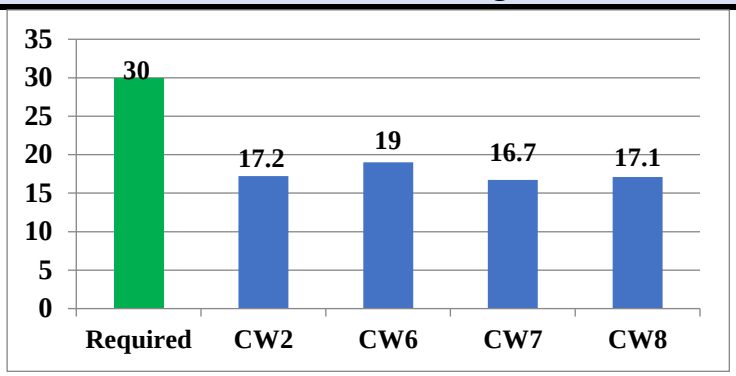


Figure 9. Actual concrete compression strength of existing concrete walls as main support of new lateral load compared to required strength by designer in MPa.

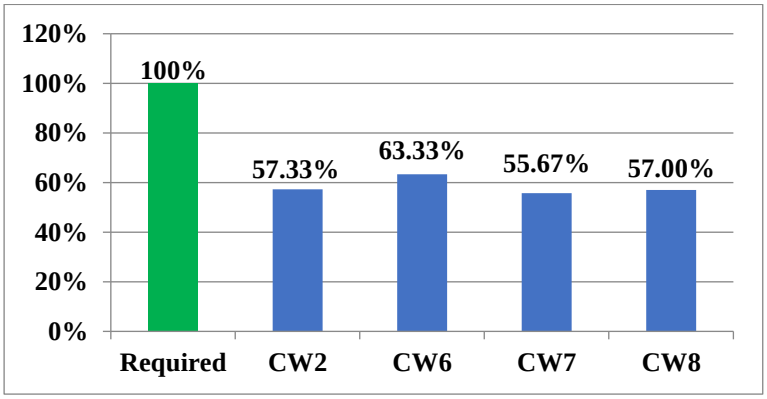


Figure 10. Percentage of actual concrete compression strength of existing concrete walls as main support of new lateral load to required strength by designer.

By reflecting these results in percentage. Figure (10) above shows that actual concrete compression strength decreases from 36.67 % to 44.33 % . From results showed in Figures (9) and (10), existing concrete main walls are considered not able to resist new lateral load.

Figure (11) illustrates the difference between required concrete strength by designer and actual concrete compression strength recorded in laboratory during concrete cylinder crash in Mega Pascal (MPa) of concrete walls (CW1,CW3,CW4,and CW5) which considered as supports to resist lateral displacement due to new lateral loads. Results show that concrete strength of these walls is very weak too. The difference various from 13.74 to 18.80 MPa.

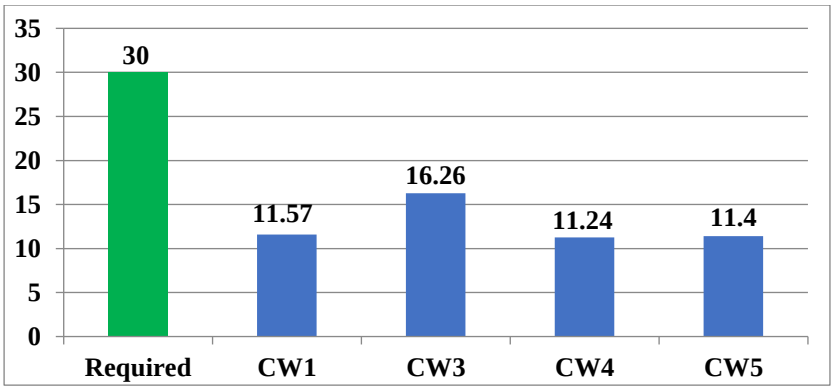


Figure 11. Actual concrete compression strength of existing concrete walls as lateral support of new lateral displacement compared to required strength by designer in MPa.

By reflecting these results in percentage. Figure (12) bellow illustrates that actual concrete compression strength decreases from 45.80 % to 62.50 % . From results showed in Figures (11)

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and (12), existing concrete lateral supporting walls are considered not able to resist new lateral load.

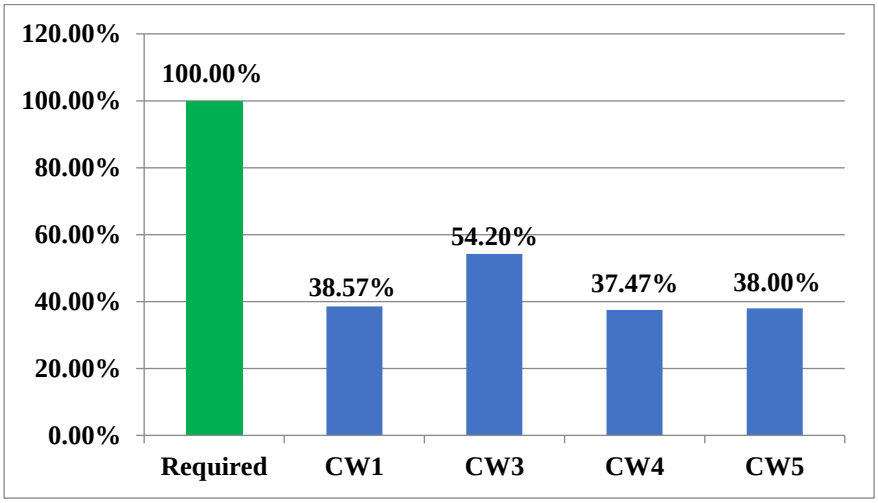


Figure 12. Percentage of actual concrete compression strength of existing concrete walls as lateral support of new lateral displacement compared to required strength by designer.

Concrete stress

Base on limit of concrete stress according to ACI 318-19 [1], the required limit is considered as 60 % of compression strength (0.60 * 30 = 18 MPa), nevertheless the actual limit is (0.60*actual compression strength), on the other hand comparing those limits with applied stress calculated based on maximum applied reactions through structure analysis indicated in table (3) reaches a value of 90.5 MPa. Figure (13) bellow illustrates Comparison of allowable existing concrete stress with an applied stress. Based on that all shear walls are not safe to resist new forces become from new space frame.

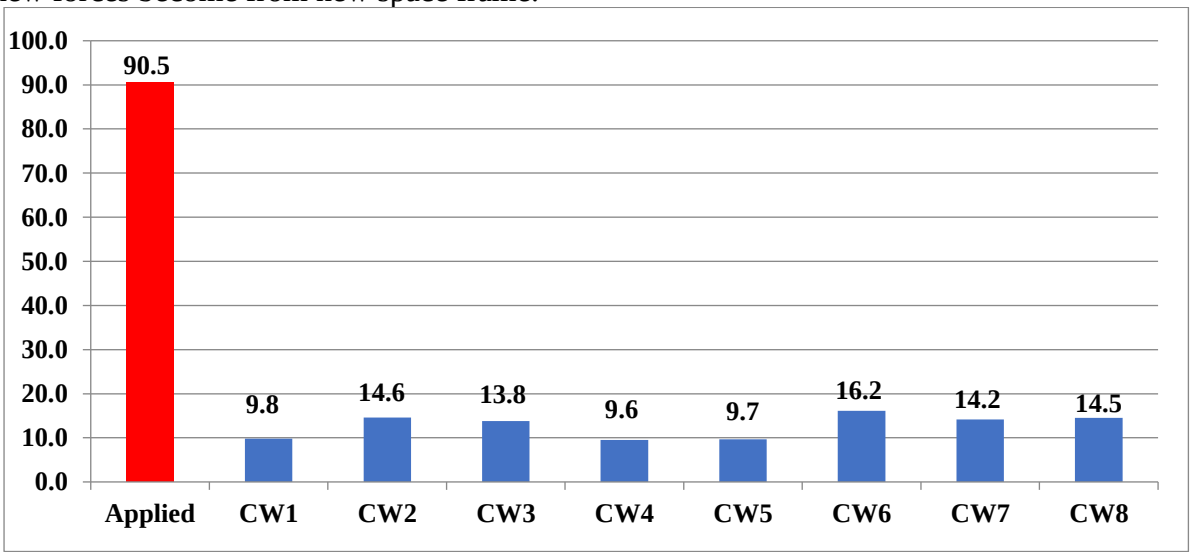


Figure 13. Comparison of allowable existing concrete stress with applied stress in MPa.

Density of concrete

By considering that normal density of concrete as 100 % of (2400 kg/m3), the ratio of density of concrete weight before crash of concrete cores samples can be indicated in figure (14) which shows that existing concrete is low dense about 93 % of normal concrete, that leads chemical components attached existing concrete.

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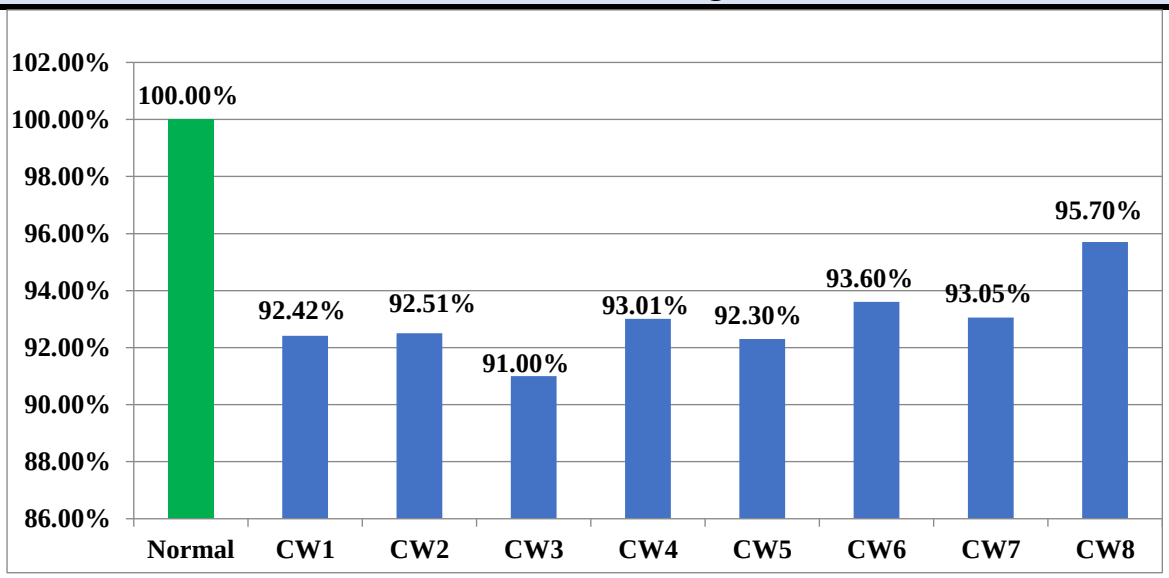


Figure 14. Percentage ratio of concrete density of existing walls verses normal density of concrete.

Lateral Displacement

According to BS EN 1990-2023 [4] maximum horizontal displacement is h/500, applicable to building blocks, and for a height of building of h = 42 m, the permissible deformation is:
h/500 = 42/500 = 0.084 m = 8.4 cm
Figure (15) illustrates calculated deformation using ETABS which exceeds the permissible limit prescribed by the applicable standards.

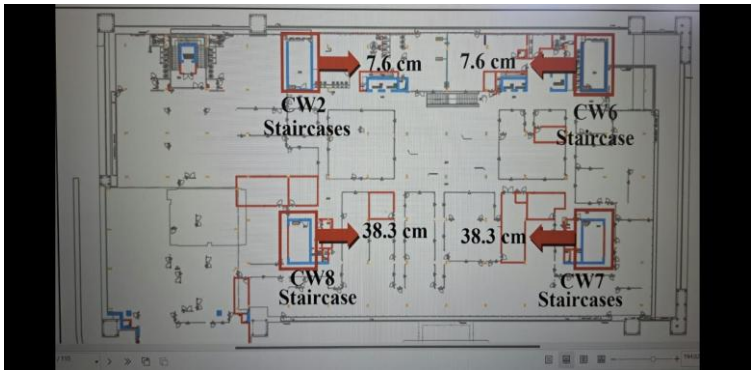


Figure 15. Calculated lateral displacement of building due to new lateral loads of space frame.

Following the various existing concrete shear walls modeling analysis regarding the loads induced by wind from space frame and the existing building, the lateral displacement of the concrete wall staircases has generated significant lateral forces that the existing structure is unable to resist. Hence, the concrete wall does not have sufficient capacity to withstand the wind loads transferred from the space frame. On the other hand it can be said that the new architectural view of building proposed by designer cannot be supported on existing concrete shear walls.

Chemical results

The sulfate contents measured in the concrete samples taken from concrete shear walls ranged from 0.56 % to 0.94 % for sulfate (SO_4) and from 0.47 % to 0.78 % for sulfur trioxide (SO_3) as shown in figures (16 and 17) respectively. These values are significantly high and exceed the limits generally accepted for durable concrete, typically below 0.5–0.6% under moderate exposure conditions, in accordance with NF P18-011 [2] and EN 206 [3]. Such sulfate

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concentrations indicate the occurrence of internal sulfate attack, promoting the formation of corrosion of steel reinforcement, expansion of the cement paste, development of internal microcracking, and progressive concrete spalling as showing in figure (3).

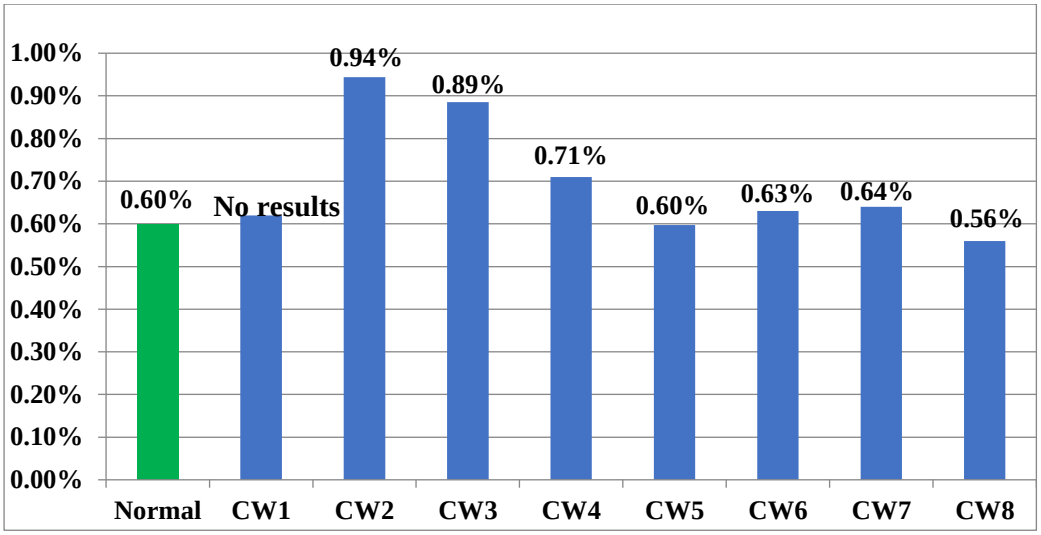


Figure 16. Average of sulfate contents (SO_4) in existing concrete shear walls.

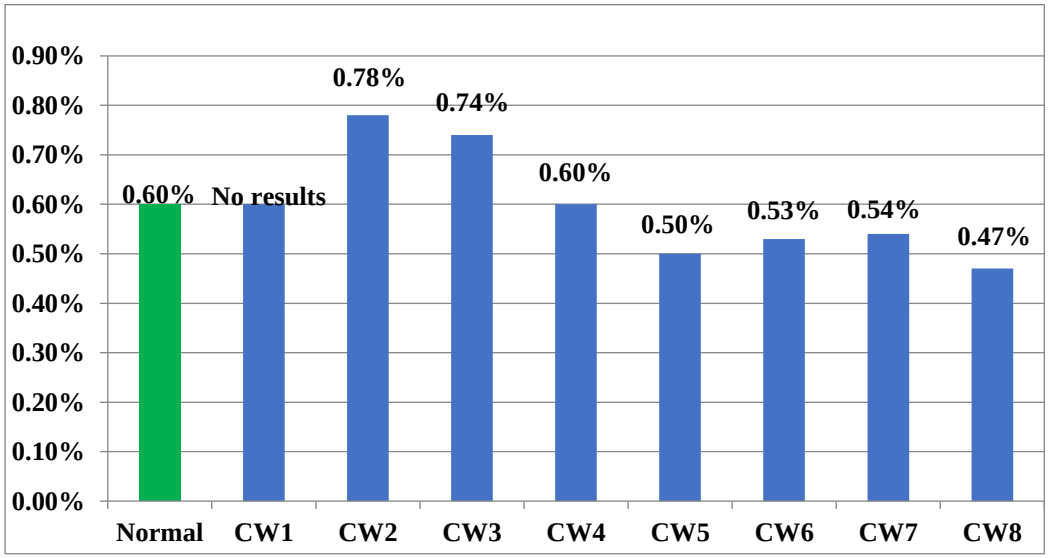


Figure 17. Average of sulfur trioxide contents (SO_3) of existing concrete shear walls.

The chloride (CL) content measured in the concrete samples taken from concrete shear walls ranged from 0.0049 % to 0..009 % as shown in figure (18). These values are significantly low and do not exceed the limits generally accepted for durable concrete. According to ACI 318-19 [5] should be below 0.15 % by the weight of cement under moderate exposure conditions. On the other hand results show that the exists of chloride with the exists of other components in concrete leads to corrosion of steel reinforcement and concrete spalling.

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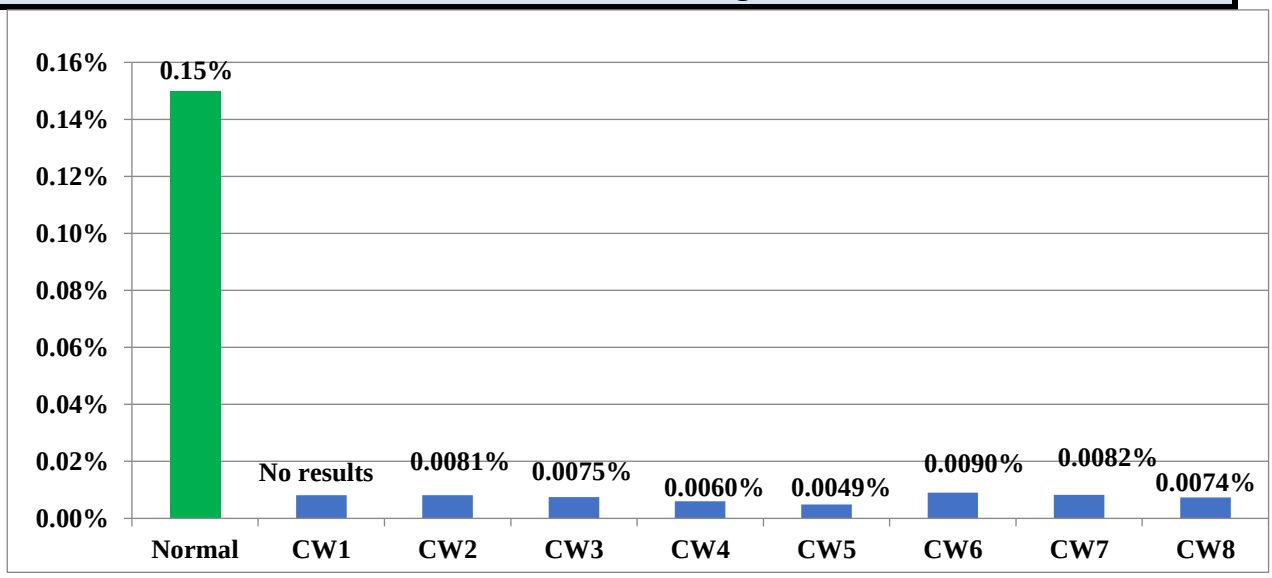


Figure 18. Average of chloride contents (CL) of existing concrete shear walls.

The total dissolved soluble (T.D.S) like (Calcium, Sodium, and mineral salts) content measured in the concrete samples taken from concrete shear walls ranged from 0.5231 % to 0.7076 % as shown in figure (19). These values are significantly high and exceed the limits generally accepted for durable concrete. According to ASTM C1602 [6] should be below 0.20%. The increase of dissolved soluble in concrete leads to decrease of its mechanical properties.

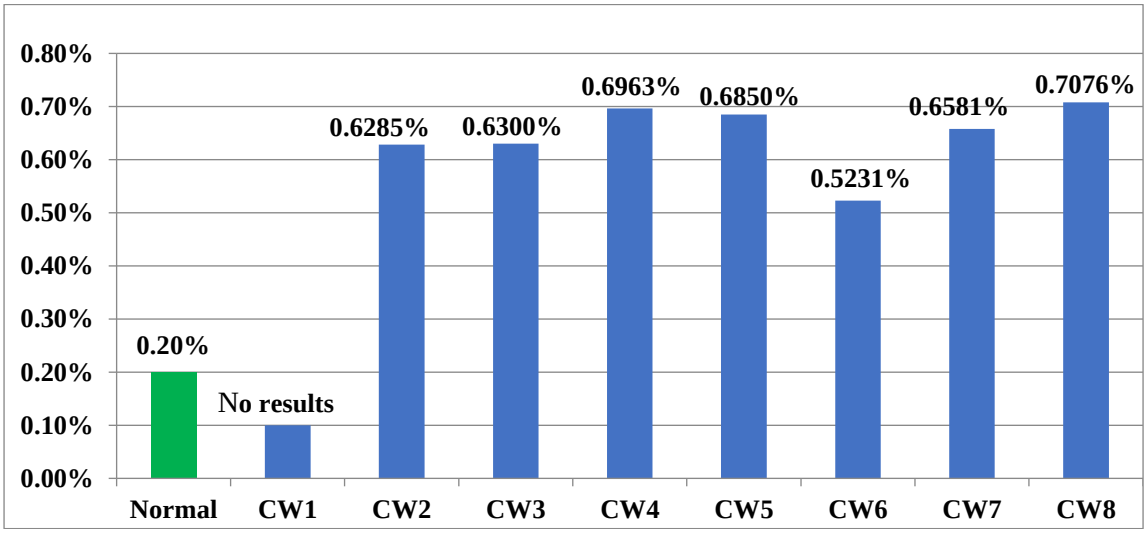


Figure 19. Average of dissolved soluble (T.D.S) of existing concrete shear walls.

The hydrogen ion (pH) content measured in the concrete samples taken from concrete shear walls ranged from 12.49 to 12.66 as shown in figure (20). These values are significantly high and exceed the limits generally accepted for durable concrete. According to IS 456 -2000 [7] should be below 6 to 8. The increase of hydrogen ions in concrete due to carbonation leads to corrosion of steel reinforcement.

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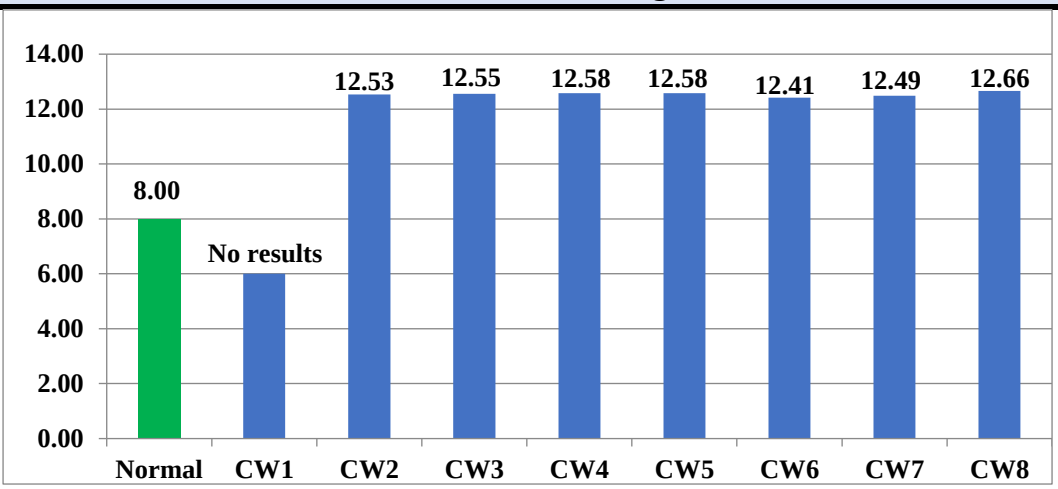


Figure 20. Average of hydrogen ions (pH) of existing concrete shear walls.

The carbonation depth is danger in concrete if it exceeds 80 % of concrete cover according to SIA 262-2025 [8]. Carbonation depth measured in the concrete samples taken from concrete shear walls ranged from 38.3 mm to 74.15 mm as shown in figure (21). The values exceed 80 % of concrete cover of (40 mm), so concrete of shear walls considered as not durable and should be repaired.

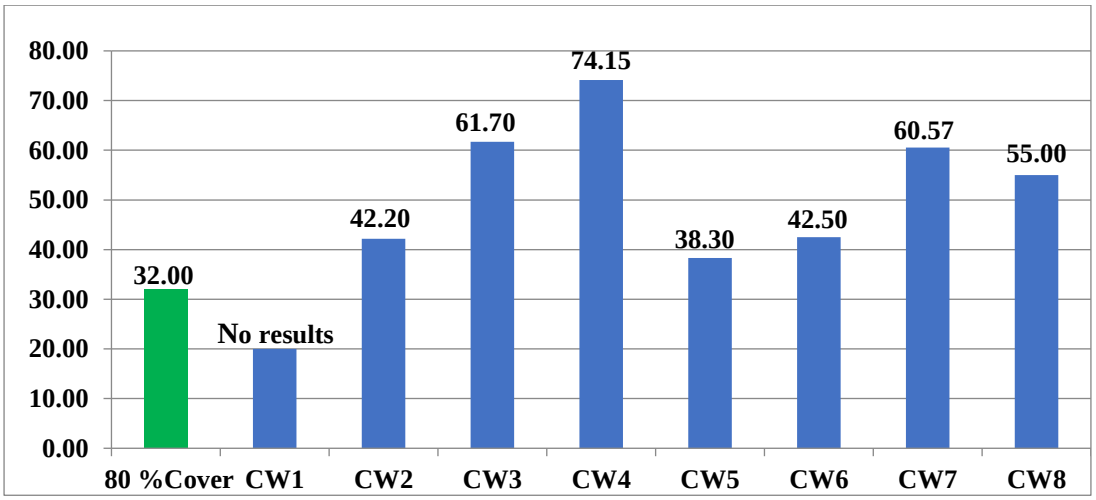


Figure 21. Average of carbonation depth of existing concrete shear walls compared to allowable value 80 % concrete cover in mm.

Conclusion

Based on the experimental results discussed in this research, several conclusions can be drawn as follow:

1- Concrete compression strength of existing concrete shear walls is very low, it is less than the required with about 50 %.
2- Existing concrete shear walls is low dense which leads chemical components attacked existing concrete. The density of concrete is about 93 % of normal concrete.
3- All shear wall are not safe to resist new forces become from new space frame if it is applied with high stress on concrete of 90 MPa, Whereas the existing concrete is able to resist 13 MPa.
4- Existing concrete shear walls do not have sufficient capacity to resist new lateral loads transferred from the space frame which leads to displace the building laterally with about 38.3 cm, whereas the allowable displacement is 8.4 cm.

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5- Sulfate contents (SO_4) in existing concrete shear walls is exceeds the normal limit with about 18 %. This leads to concrete microcracking and formation of corrosion of steel reinforcement and spalling of concrete.
6- Sulfur trioxide contents (SO_3) in existing concrete shear walls is exceeds the normal limit with about 5 %. This leads to concrete microcracking and formation of corrosion of steel reinforcement and spalling of concrete.
7- Although chloride (CL) content in existing concrete shear walls is less than the limits with 95 % but it effected the existing walls with the presence of other chemical components.
8- The total dissolved soluble (T.D.S) of existing concrete shear walls are significantly high and exceed the limits with about 220 %. So existing concrete not accepted as durable concrete.
9- The hydrogen ion (pH) content in existing concrete shear walls is exceeds the normal limit with about 57 %, this leads to corrosion of steel reinforcement.
10- Carbonation depth in existing concrete shear walls exceeds concrete cover limit with about 22 mm. So existing concrete not accepted as durable concrete.
11- Based on all experimental results of existing Reinforced concrete shear walls, the walls will not carry new lateral loads safely. On the other hand repair of existing concrete shear walls must be done.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

Notation

h = overall height of building in (m).

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