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1st International Conference on Recent Academic Studies
May 2-4, 2023 : Konya, Turkey

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CONDITION ASSESSMENT OF BUILDING CONCRETE STRUCTURES USING NDTs – CASE STUDY

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Abstract – The quality of concrete and serviceability for three old buildings utilizing non-destructive testing (NDT) method of rebound hammer (RH) and ultrasonic pulse velocity (UPV) was assessed in the present study. Identification, classification and evaluation of in-situ concrete have helped us to decide whether these three buildings need to be repaired and in result extent their service life or it is not acceptable for its intended usage and they need to be demolished. To evaluate the level of deterioration in historical and fire-damaged buildings or infrastructures, non-destructive testing (NDT) methods can be used. In fact, NDT method employs inspection techniques to evaluate engineering properties to see if it is acceptable for its intended usage that does not need specimens to be crushed like the destructive testing method. The NDT method of rebound hammer (RH) and ultrasonic pulse velocity (UPV) in combination with conventional methods such as internal and external visual inspection and concrete color change to locate deterioration was used to evaluate the quality of concrete structures for three old buildings. According to the results obtained the RH and UPV can be used as reliable tools to predict the mechanical properties of concrete structures subjected to fire and/or weathering deterioration. In addition, combining the two NDTs decreased inaccuracies caused by utilizing one method alone to evaluate concrete quality.

Keywords – Concrete; Deterioration; Non-Destructive Testing; Rebound Hammer; Strength; Structure; UPV.

I. INTRODUCTION

Regular inspection and assessment of concrete structures' quality is very important at various stages of a structures' existence, especially for infrastructures and historical buildings deteriorating for which advanced inspection procedures are required. For such concrete structures, it is necessary to determine whether the structure is suitable for its designed usage or not, which examining should be done without damaging the structure. Weather and fire resistance are the main advantages of reinforced concrete over other construction materials. However, when exposed to very high temperatures, the overall concrete expansion and decrease in tensile strength of steel result in the deterioration and structural collapse of reinforced concrete [1, 2]. Concrete deterioration can also result from inadequate design or construction, operational accidents, chemical attack, corrosion, loading, aging processes, or any combination of these [3]. Therefore, there is a need for better and advanced inspection techniques instead of human visual inspection to locate hidden damages for monitoring and identify the exact portion of the deterioration of infrastructures such as bridges, dams and even pipelines. From engineering point of view assessing the condition of a structure is necessary for its safety and maintenance process to support economics and to meet sustainable development's goals [4-6]. To evaluate the level of deterioration and to ensure the quality of concrete in historical and fire-damaged buildings or infrastructures, non-destructive testing (NDT) methods can be used. In fact, NDT method employs inspection techniques to evaluate engineering properties to see if it is acceptable for its intended usage that does not need specimens to be crushed like the destructive testing method [7-9]. For some important reinforced concrete structures such as dams and bridges, this method can determine and observe the changes of properties and durability of concrete in the long-term. It can locate and estimate the size of cracks, voids, honeycombing, and other defects within a concrete building with flaws [8, 9]. Furthermore, the NDT method can be carried out on structural elements mostly before and after repair work to justify the increase in strength after the repair work [9]. According to the recently published research there are five main factors should be considered which lead to the specification in the design of the NDT method or provide an alternative to NDT techniques if it is not suitable for solving a particular problem as follows: the technique penetration capability, the measurements resolution requirements, the contrast in physical properties between the target and its surroundings, the level of noise of the techniques, and the technique historical reputation in its use in the construction of the structure [10]. Rebound hammer (RH) and ultrasonic pulse velocity (UPV) are NDT methods for determining the overall quality of concrete in a quick and easy way. The surface hardness of concrete, which is assumed to be proportional to the compressive strength of concrete, can be measured by a RH device [11]. The strength of a concrete structure can be determined after determining the correlation between compressive strength and RH. The strength of concrete rises as the RH rises and is influenced by a number of factors such as the type of cement and aggregate used, the surface condition and moisture content of the concrete, the curing and age of the concrete, the carbonation of the concrete surface, etc. Furthermore, the rebound index is a measure of concrete's compressive strength up to a certain depth below the surface. According to the ASTM, rebound values will not identify interior cracks, defects, or variability throughout the cross section, which can be determined by other types of NDT methods [12]. Another technique of NDTs is UPV that used to evaluate the concrete structures. The UPV can be used for determining the homogeneity of concrete and determining the presence of cracks, voids, and other imperfections [13, 14]. However, according to Pedreros et al. (2019) [15] there are some factors such as cracks and/or composition that do not affect the compressive stiffness of the concrete to the same extent as they affect the magnitude of the UPV. Therefore, the UPV values alone are not reliable for the prediction of the concrete compressive stiffness. Instead, the combination of several NDT methods such as UPV and RH should be employed for results that are more accurate [15]. RH determine surface hardness while UPV shows travel of compression waves within concrete heterogeneous materials. Thus, these two parameters can be used to predict concrete compressive strength [16]. The main aim of the present study was to inspect and evaluate the quality and structural health assessment of concrete of three old buildings' structures using NDT method and assess the current condition of these buildings to conduct repairing and maintenance adequately or, decide to be demolished. Although, there is similar work in the literature, the purpose of this study was to encourage the local government and construction companies to conduct regular inspection using advanced technology for monitoring the deterioration of infrastructures as assessing the condition of a structures is very important in safety, maintenance process, economics and sustainability point of views. The outcome of this research would be communicated to professionals working in construction industry and will be beneficial locally and globally.

II. Materials and Method

The three old buildings are located in a historical district of Shaqlawa, Erbil, Iraq. The buildings have been constructed between 1960 and 1970. The buildings were mixed reinforced concrete and masonry structures. One of those was a real fire-damaged building; however, according to the information received from the local officials, the fire duration was not too long. Testing included RH and UPV in combination with conventional methods such as internal and external visual inspection and concrete color change to locate deterioration and predict the compressive strength of concrete structures and for the assessment of the expected service life of the buildings (Figure 1). Due to the limits of each of the two tests for predicting concrete strength, both UPV and RH tests were employed to reduce the inaccuracies caused by the effect of the environment.

Figure 1: Three old and fire-damaged buildings

A. Rebound Hammer

Before RH testing, the rough surfaces of beams and columns at least 20mm far from the edge were selected and the surfaces were smooth, clean, and dry. Moreover, the loose parts were rubbed off. To obtain more accurate results by decreasing the measurement distance, 15 beam readings and 19 readings in the columns were collected. Classification of the quality of concrete based on RH is shown in Table 1. The RH device (Figure 2) calibrated against the test steel anvil with hardness of around 5000 MPa which was provided by the manufacturing company and again to ensure the accuracy of the measurement and operation at the end of the test the same procedure was repeated. The hammer (Figure 3) was held at right angles (90 degrees) to the concrete surface while collecting measurement values. The test was carried out horizontally on vertical surfaces, as well as vertically upward or downwards on horizontal surfaces [12-14]. All RH data are presented in Appendix.

Table 1: Classification of the quality of concrete based on RH [17]

RH	Quality of Concrete
>40	Very Good
30-40	Good
20-30	Fair
<20	Poor

Figure 2: RH device used in the present study

Figure 3: Collecting RH values of beams and columns

B. Ultrasonic Pulse Velocity

Each concrete member was subjected to UPV testing in accordance with British standards [18]. The pulse velocities were measured between opposite surfaces in a direct technique. There were 15 beam readings and 19 readings in the columns with 3 or 4 readings at different selected surfaces of each column and beam. The transducers were placed precisely opposite each other on opposite sides of the concrete structure (Figure 5). The mean is used in this test as well as the strength derived from to create a correlation curve between the two properties of UPV and strength. Before beginning UPV testing and to ensure the accuracy of the measurement and operation, the device (Figure 4) was calibrated and again at the end of the test the same procedure was repeated. It's done by using a standard calibration rod that comes with the device to measure the transit time. For this study, direct transmission was used and the velocity criterion for engineering quality of concrete grading is shown in Table 2. The UPV was measured by V = L / T. Where: V = pulse velocity, L = path length, and T = time taken by the pulse to traverse the path length. All UPV data are presented in appendix.

Figure 4: UPV device used in the present study

Figure 5: Collecting UPV values on beams and columns

Table 2: Classification of the quality of concrete based on pulse velocity [19]

Higher than 4.5 Km/s	Excellent
3.5 - 4.5 Km/s	Good
3 - 3.5 Km/s	Medium
Lower than 3 Km/s	Doubtful

III. RESULTS AND DISCUSSION

A. *Rebound Hammer*

A.1 Building 1

The results of the Rebound Hammer (RH) examination for determining the overall concrete quality for building 1 were assessed as "poor/fair" condition because the building is too old and has lots of cracks on the columns and beams which can be seen by human visual inspection. May be another reason is having inappropriate mix proportion, thermal effect, not doing curing properly for the concrete, environmental deterioration, or that the concrete is made from low quality materials as the deteriorating effect of weathering was spread on almost all parts of the building and severely degraded columns and beams which matches well with lower concrete RH-based compressive strength values [20-23]. According to the results (Table 3) obtained on different concrete structures (Figure 6) and damage identifications, we concluded that this building is not suitable to be repaired and from the engineering point of view it needs to be demolished.

A.2 Building 2

The results of the RH for building 2 for determining compressive strength and overall quality are assessed as "good/very good" layers. The results obtained in this old building showed that they have less visible cracks in the surface. We calculated the compressive strength from those data presented in Appendix. According to the results (Table 4) obtained on beams and columns (Figure 7) and structural damage assessment, we concluded that this building may be suitable to be repaired and to some extent the service life of the building.

A.3 Building 3

Building 3 was a real fire-damaged building. According to the results obtained for the RH test, due to the short duration of fire and structures undamaged, the concrete is assessed as “good/very good” layer. We calculated the compressive strength from those data shown in Appendix. The RHs were not greatly reduced as fire couldn’t affect the concrete surface directly due to the short time of fire. RH purely gives estimation of strength on the external boundary of concrete structure and is unable to predict internal integrity of bond within concrete; therefore, RH alone is not an accurate predictor of compressive strength inside the structure. According to the data (Table 5) on building structures (Figure 8) and structural damage assessment, we concluded that building 3 is suitable to be repaired and in result to extent the service life of the building.

B.UPV

B.1 Building 1

Similar to the Rebound Hammer values, according to the UPV values found in building 1, the quality of the concrete structures is classified as poor/doubtful concrete and after taking the structural damage assessment into consideration, we suggest that building 1 is not suitable to get repaired. UPV values decrease in deteriorating condition parts of the concrete structures. It is worth to mention that the presence of voids and cracks in damaged and deteriorated concrete force the ultrasonic waves to adopt the longer travel path between two transducers due to which less UPV values were attained. Table 6 shows the data and results for UPV values for building 1 concrete structures (Figure 6).

B2. Building 2

After collecting the UPV data for building 2, the quality of the concrete can be classified as good concrete. The relationship between UPV and strength is affected by a number of factors including age, curing conditions, moisture condition, mix proportions, type of aggregate, and type of cement [24]. Table 7 shows the data and results for UPV for building 2 structures (Figure 7). According to the UPV data obtained and structural damage assessment, we concluded that building 2 is suitable to be repaired and in result to extent the service life of the building. According to the equations reported in the literature and the collected data of the present study, for any value of (UPV), there is a wide range of compressive strength. For instance, for the value of UPV equals to 4.1 km/s, the values of compressive strength are ranging from (20.07MPa) to (36.47 MPa). This can be used as a main indicator of the relationship between (UPV) and concrete compressive strength. Similar results have been reported elsewhere [25, 26]. We developed a new equation in the present study’s UPV values shown in Figure 9 that correlated out of the ten equations reported by other researchers.

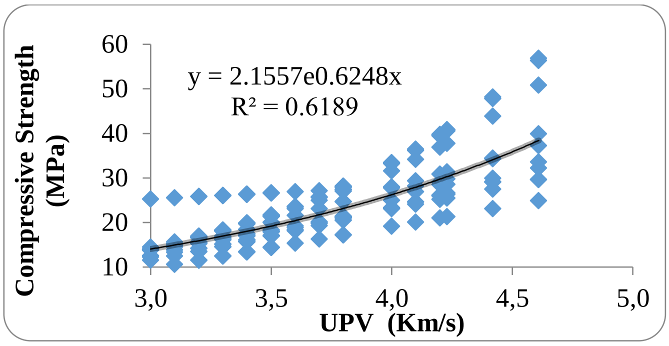

Figure 9: Correlation between the present and previous studies

For example, if the velocity is 4.1 km/s, the compressive strength in equation, $C = 2.8\ e^{0.53v}$ is equal to 24.60 MPa but in our equation $y = 2.1557e^{0.6248x}$ is equal 27.93 MPa which is similar. Another study’s equation $C = 2.016\ e^{0.61v}$ for the same velocity is equal to 24.58 MPa but in our equation $y = 2.1557e^{0.6248x}$ is equal to 27.93MPa; may be the difference is due to their recommendation that the surface of concrete should be wetted before testing. In another investigation, the following equation to calculate the approximate value of concrete compressive strength regardless of mix proportions has been proposed. In this equation $Y= 0.3161\ e^{(1.03\ Vn)}$, if the velocity is 4.1km/s, the strength is equal to 21.57 MPa. Furthermore, if we compare our results with the study reported in Table 7, in the equation $fc = 0.0011\ e^{(2.315\ V)}$ the result is equal to 14.57 MPa if the velocity is 4.1km/s [27-30]. According to the abovementioned details compressive strength seems to be increasing with increase in UPV and generally an exponential correlation exists between UPV and compressive strength.

B3. Building 3

After collecting the UPV data (Table 8) on concrete structures (Figure 8) and analysing the results for building 3, the overall quality of the concrete structures can be classified as “good” concrete. The layer between paste and aggregate in concrete is called interfacial transition zone (ITZ) which generally defined as the weakest link in the concrete structure. In this case it didn’t become fragile in this fire-damaged building due to the low fire time and low temperature exposure. In result strength and durability of concrete structures may be less affected. Similar to the results found for building 2, according to the UPV data obtained and the structural damage assessment in building 3, we suggest that building 3 is suitable to be repaired and in result to extent the service life of the building. According to the results obtained, data analysis, justification and discussion the NDTs can provide reliable assessments to local government officials and landlords of the buildings as decision makers. The decision that to what extent the building needs to be strengthened and which method of repair to be decided must be based on data analysis that shows if the levels of safety demanded by the national and international standard’s recommendations are met. The strengthening and repair method will mainly depend on the structural scheme and materials used for the construction of the buildings.

IV. CONCLUSION

In the present study, our main aim was to assess the overall quality of concrete utilizing two non-destructive testing (NDT) techniques of rebound hammer (RH) and ultrasonic pulse velocity (UPV) for three old buildings which one of them was a real fire-damaged. The reason we decided to use two NDTs of UPV and RH in the present study is because combining the two procedures decreased inaccuracies caused by utilizing one method alone to evaluate concrete quality. Identification, classification, and evaluation of in-situ concrete were helping us to decide whether these three buildings need to be repaired and the extent their service life or their service life has been ended and they need to be demolished. According to the RH and UPV results obtained on columns and beams, and the predicted compressive strength and their comparisons and correlations in the present investigation and the published literature, the following conclusions can be drawn:

1- The overall quality of concrete in building 1 is evaluated as “poor” and from an engineering point of view its service life has been ended and needs to be demolished.
2- The overall quality of concrete in building 2 is identified as “good/very good” and from the structural concrete assessment point of view, the building can be repaired to an extent the service life. According to the correlation between compressive strength and UPV reported by many studies in the literature and UPV values of the present investigation, a novel Equation of $y = 2.1557e^{0.6248x}$ has been created with strong correlation of $R^2 = 0.6189$.
3- Although building 3 was a fire-damaged building, however, the overall quality of the concrete is classified as “good/very good” and the building can be repaired or renovated to some extent the service life.

At the end, the results from NDT method are reliable; however, for each case further research using especial NDT techniques and in some cases even destructive tests are required. Using advanced NDT methods as well as advanced UPV and RH devices that can penetrate into the depth of in-situ concrete structures of buildings and infrastructures to evaluate the quality of concrete is much recommended.

ACKNOWLEDGMENT

The authors gratefully acknowledge the technical support provided by the civil engineering laboratory at faculty of engineering, Soran University.

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Table 3: RH data for building 1

Location	Average of Rebound Hammer Points	Building 1 Pridicion Fcu (Mpa)	Qulity of concrete
Column A1	27	23	Fair
Column A2	29	25	Fair
Column A3	27	23	Fair
Column B1	21	18	Fair
Column B2	19	16	Poor Concrete
Column B3	23	20	Fair
Column C1	21	18	Fair
Column C2	26	22	Fair
Column C3	23	20	Fair
Column D1	27	23	Fair
Column D2	27	23	Fair
Column D3	26	22	Fair
Column E1	19	16	Poor Concrete
Column E2	18	15	Poor Concrete
Column E3	21	18	Fair
Column F1	27	23	Fair
Column F2	31	26	Good
Column F3	29	25	Fair
Column F4	29	25	Fair
Beam A1	23	20	Fair
Beam A2	26	22	Fair
Beam A3	21	18	Fair
Beam B1	19	16	Poor Concrete
Beam B2	21	18	Fair
Beam B3	19	16	Poor Concrete
Beam C1	26	22	Fair
Beam C2	29	25	Fair
Beam C3	31	26	Good
Beam D1	21	18	Fair
Beam D2	26	22	Fair
Beam D3	27	23	Fair
Beam E1	23	20	Fair
Beam E2	19	16	Poor Concrete
Beam E3	21	18	Fair
		Sum of Fcu / 34= 21 Mpa	Fair/Poor

Table 4: RH data for building 2

		Building 2	
Location	f Rebound Hamı	Pridicion Fcu (Mpa)	Qulity of concrete
Column A1	38	30	Good Layer
Column A2	40	34	Good Layer
Column A3	41	35	very Good Layer
Column B1	40	34	Good Layer
Column B2	39	31	Good Layer
Column B3	42	37	very Good Layer
Column C1	37	28	Good Layer
Column C2	39	31	Good Layer
Column C3	40	34	Good Layer
Column D1	44	39	very Good Layer
Column D2	42	37	very Good Layer
Column D3	43	39	very Good Layer
Column E1	41	35	very Good Layer
Column E2	40	34	Good Layer
Column E3	43	39	very Good Layer
Column F1	39	31	Good Layer
Column F2	41	35	very Good Layer
Column F3	42	37	very Good Layer
Column F4	41	35	very Good Layer
Beam A1	41	35	very Good Layer
Beam A2	39	31	Good Layer
Beam A3	38	30	Good Layer
Beam B1	40	34	Good Layer
Beam B2	42	37	very Good Layer
Beam B3	41	35	very Good Layer
Beam C1	40	34	Good Layer
Beam C2	42	37	very Good Layer
Beam C3	44	39	very Good Layer
Beam D1	39	31	Good Layer
Beam D2	37	28	Good Layer
Beam D3	39	31	Good Layer
Beam E1	43	39	very Good Layer
Beam E2	42	37	very Good Layer
Beam E3	44	39	very Good Layer
		Sum of Fcu / 34= 35 Mpa	Good/Very Good

Table 5: RH data for building 3

		Building 3	
Location	bound H	idicion Fcu (Mp	Qulity of concrete
Column A1	40	34	Good Layer
Column A2	41	35	very Good Layer
Column A3	39	31	Good Layer
Column B1	42	37	very Good Layer
Column B2	43	39	very Good Layer
Column B3	41	35	very Good Layer
Column C1	38	30	Good Layer
Column C2	40	34	Good Layer
Column C3	41	35	very Good Layer
Column D1	39	31	Good Layer
Column D2	37	28	Good Layer
Column D3	39	31	Good Layer
Column E1	40	34	Good Layer
Column E2	42	37	very Good Layer
Column E3	44	39	very Good Layer
Column F1	40	34	Good Layer
Column F2	41	35	very Good Layer
Column F3	40	34	Good Layer
Column F4	42	37	very Good Layer
Beam A1	43	39	very Good Layer
Beam A2	42	37	very Good Layer
Beam A3	40	34	Good Layer
Beam B1	39	31	Good Layer
Beam B2	41	35	very Good Layer
Beam B3	40	34	Good Layer
Beam C1	42	37	very Good Layer
Beam C2	41	35	very Good Layer
Beam C3	41	35	very Good Layer
Beam D1	44	39	very Good Layer
Beam D2	42	37	very Good Layer
Beam D3	43	39	very Good Layer
Beam E1	42	37	very Good Layer
Beam E2	44	39	very Good Layer
Beam E3	40	34	Good Layer
		Sum of Fcu / 34= 35	Good/Very Good

Table 6: UPV data for building 1

Location	Time (S)	UPV Building 1 Distance (mm)	Velocity (Km/S)	Qulity of concrete
Column A1	186	250	1.3	Doubtful
Column A2	184	250	1.4	Doubtful
Column A3	185	250	1.4	Doubtful
Column B1	177	250	1.4	Doubtful
Column B2	173	250	1.4	Doubtful
Column B3	176	250	1.4	Doubtful
Column C1	180	250	1.4	Doubtful
Column C2	185	250	1.4	Doubtful
Column C3	183	250	1.4	Doubtful
Column D1	182	250	1.4	Doubtful
Column D2	187	250	1.3	Doubtful
Column D3	185	250	1.4	Doubtful
Column E1	174	250	1.4	Doubtful
Column E2	175	250	1.4	Doubtful
Column E3	172	250	1.5	Doubtful
Column F1	181	250	1.4	Doubtful
Column F2	184	250	1.4	Doubtful
Column F3	187	250	1.3	Doubtful
Column F4	185	250	1.4	Doubtful
Beam A1	253	300	1.2	Doubtful
Beam A2	249	300	1.2	Doubtful
Beam A3	256	300	1.2	Doubtful
Beam B1	240	300	1.3	Doubtful
Beam B2	247	300	1.2	Doubtful
Beam B3	243	300	1.2	Doubtful
Beam C1	252	300	1.2	Doubtful
Beam C2	258	300	1.2	Doubtful
Beam C3	251	300	1.2	Doubtful
Beam D1	260	300	1.2	Doubtful
Beam D2	263	300	1.1	Doubtful
Beam D3	265	300	1.1	Doubtful
Beam E1	245	300	1.2	Doubtful
Beam E2	250	300	1.2	Doubtful
Beam E3	249	300	1.2	Doubtful
		Average = 1.3 Km/S		Doubtful

Table 7: UPV data for building 2

		UPV		
		Building 2		
Location	Time (µS)	Distance (mm)	Velocity (Km/S	Quality of concrete
Column A1	87	300	3.4	Medium
Column A2	85	300	3.5	Good
Column A3	88	300	3.4	Medium
Column B1	79	300	3.8	Good
Column B2	72	300	4.2	Good
Column B3	75	300	4	Good
Column C1	73	300	4.1	Good
Column C2	78	300	3.8	Good
Column C3	74	300	4.1	Good
Column D1	81	300	3.7	Good
Column D2	85	300	3.5	Good
Column D3	87	300	3.4	Medium
Column E1	78	300	3.8	Good
Column E2	79	300	3.8	Good
Column E3	75	300	4	Good
Column F1	84	300	3.6	Good
Column F2	89	300	3.4	Medium
Column F3	88	300	3.4	Medium
Column F4	86	300	3.5	Good
Beam A1	101	350	3.5	Good
Beam A2	103	350	3.4	Medium
Beam A3	106	350	3.3	Medium
Beam B1	108	350	3.2	Medium
Beam B2	104	350	3.4	Medium
Beam B3	107	350	3.3	Medium
Beam C1	111	350	3.2	Medium
Beam C2	116	350	3	Medium
Beam C3	113	350	3.1	Medium
Beam D1	105	350	3.3	Medium
Beam D2	102	350	3.4	Medium
Beam D3	107	350	3.3	Medium
Beam E1	100	350	3.5	Good
Beam E2	104	350	3.4	Medium
Beam E3	109	350	3.2	Medium
			Average = 3.5 Km/	Good

Table 8: UPV data for building 3

		UPV		
		Building 3		
Location	Time (µS)	Distance (mm)	Velocity (Km/S	ality of concrete
Column A1	126	400	3.2	Medium
Column A2	128	400	3.1	Medium
Column A3	130	400	3.1	Medium
Column B1	133	400	3	Medium
Column B2	135	400	3	Medium
Column B3	134	400	3	Medium
Column C1	128	400	3.1	Medium
Column C2	124	400	3.2	Medium
Column C3	129	400	3.1	Medium
Column D1	123	400	3.3	Medium
Column D2	127	400	3.2	Medium
Column D3	125	400	3.2	Medium
Column E1	131	400	3.1	Medium
Column E2	135	400	3	Medium
Column E3	137	400	2.9	Doubtful
Column F1	129	400	3.1	Medium
Column F2	132	400	3	Medium
Column F3	135	400	3	Medium
Column F4	134	400	3	Medium
Beam A1	126	400	3.2	Medium
Beam A2	130	400	3.1	Medium
Beam A3	131	400	3.1	Medium
Beam B1	129	400	3.1	Medium
Beam B2	125	400	3.2	Medium
Beam B3	127	400	3.2	Medium
Beam C1	132	400	3	Medium
Beam C2	136	400	2.9	Doubtful
Beam C3	135	400	3	Medium
Beam D1	127	400	3.2	Medium
Beam D2	123	400	3.3	Medium
Beam D3	128	400	3	Medium
Beam E1	135	400	3	Medium
Beam E2	139	400	2.9	Doubtful
Beam E3	137	400	2.9	Doubtful
			Average = 3.1 Km/S	Medium

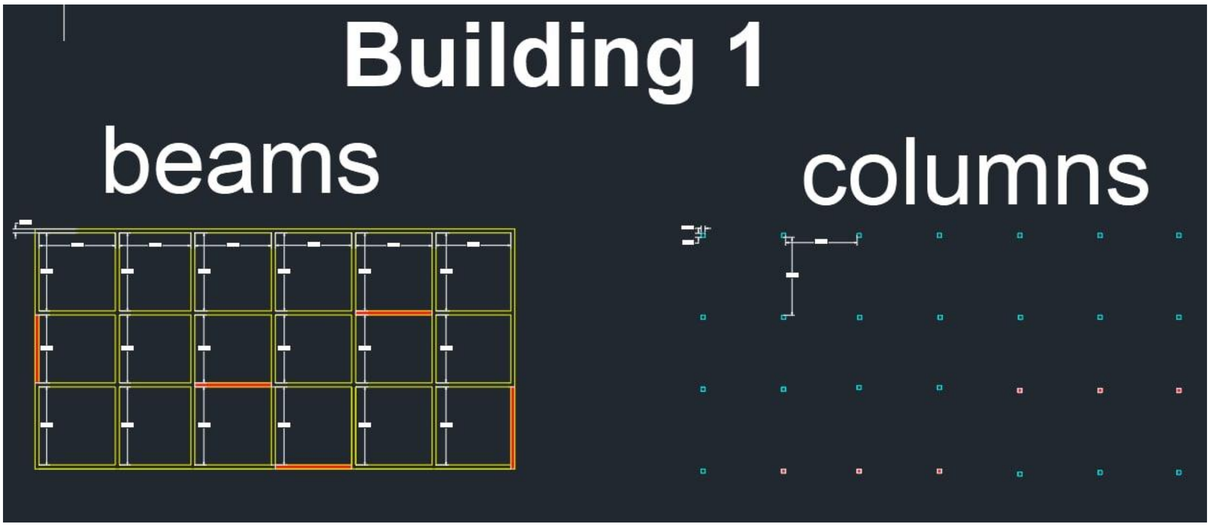

Figure 6: Selected beams and columns highlighted in red – Building 1

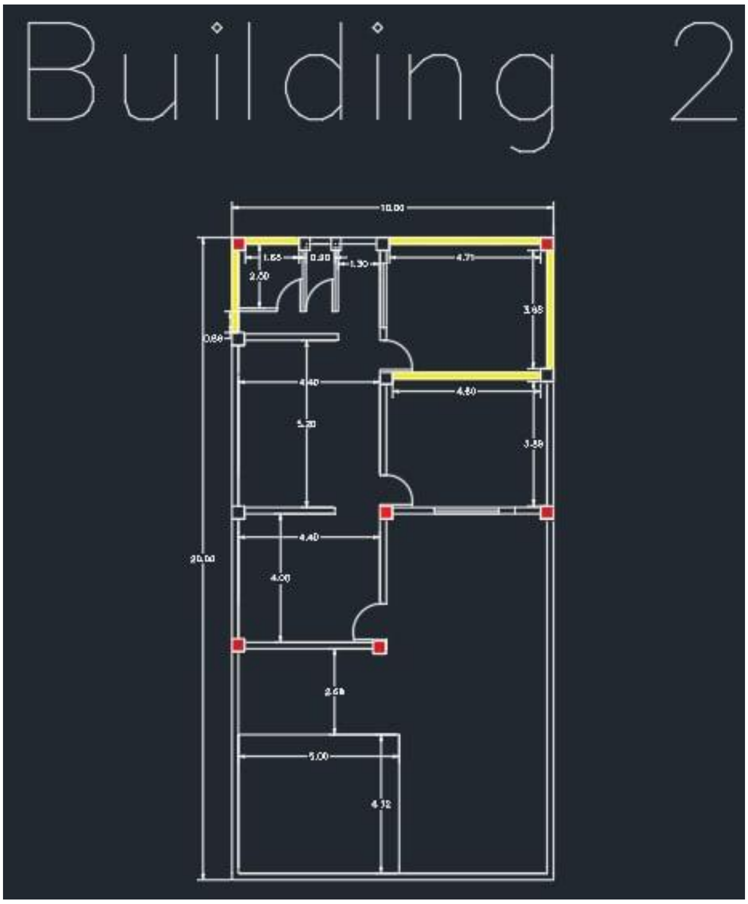

Figure 7: Selected beams and columns highlighted in red – Building 2

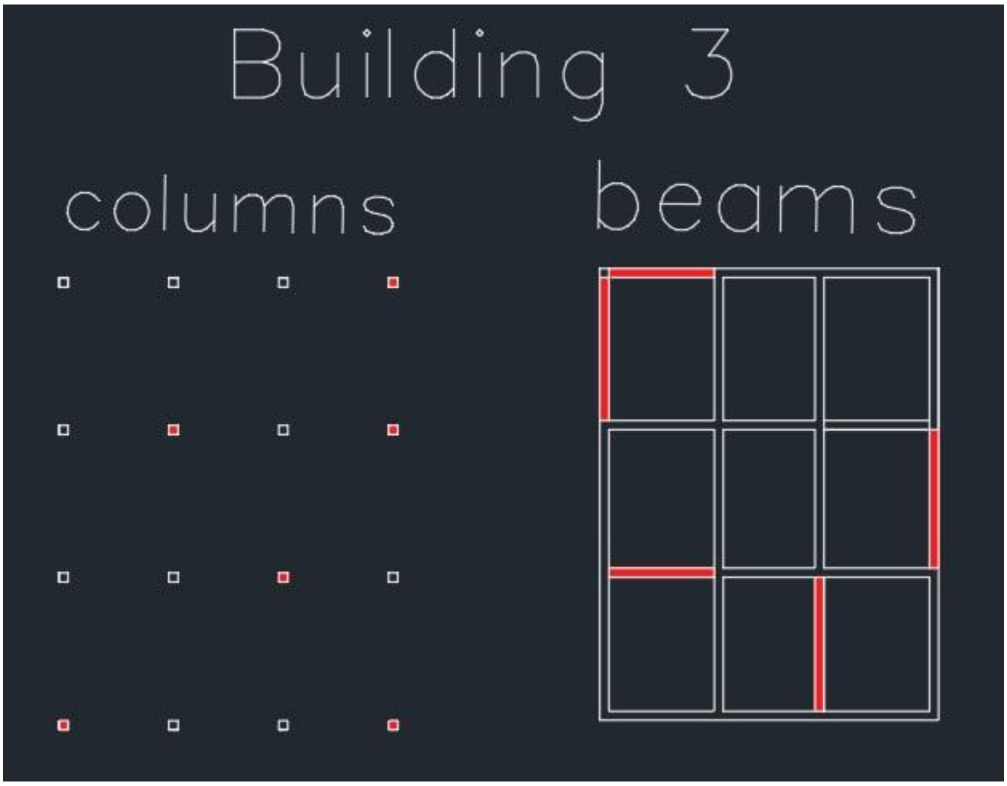

Figure 8: Selected beams and columns highlighted in red - Building 3