Majalah Ilmiah Pengkajian Industri
(Journal of Industrial Research and Innovation)
Vol. 16, No.3 December 2022 – (95-102)
Journal homepage: https://ejurnal.bppt.go.id/index.php/MIPI/index

Study of Pedestal Column Foundation of Heater Structures After a Fire Accident

Tri Handayani[1*], Puguh Triwinanto[1]

[1]*National Research and Innovation Agency, Indonesia*
*Correspondence E-mail: trih007@brin.go.id

ABSTRACTS

This paper has presented the study of concrete experiencing the fire of the pedestal column of the heater foundation structure after the fire accident. The evaluation was done with the analytical method, which was conducted to find out the actual condition of an existing structure. Structure or components of the structure are categorized as a safe condition; if its design strength is greater or equal to the required strength or $ØR_n \geq R_u$. Evaluation of the pedestal column structure with the analytical method was done by visual inspection, concrete quality inspection, cracking depth inspection, structural analysis with the finite element software and strength calculation of structure according to the requirement of SNI 2847 2013. The equipment used for concrete quality inspection is Digischmidt Hammer and PUNDIT. The result showed that there was a degradation of the concrete quality of less than 15%. However, with this condition, all of the pedestal column structures are still in a safe condition in receiving the load operation.

ARTICLE INFO

Article History:
Received 21 July 2022
Revised 19 August 2022
Accepted 13 Dec 2022

Keyword:
Concrete experiencing a fire,
Concrete evaluation,
Pedestal column,
Required strength,
Design strength.

INTRODUCTION

Concrete is one of the most resistant materials to fire compared to other materials such as steel and wood. Concrete has low heat conductivity so it can reduce heat transfer through the inside of concrete. The damage to concrete structures due to fire often occurred gradually. Damage to concrete structures can be found in many stages of the building process, which are in the construction stage or the service life of the building. The case study of this research presents the fire accident of the pedestal column structure in the service life stage.

Degradation or reducing the strength of the structure occurs in concrete structures after a fire accident. So, checking the actual condition of the structure is needed to know whether the structure is still in a safe condition, has the strength to receive the operational load, needs repair to be used or needs demolition due to the unsafe condition of the structure.

Some studies related to concrete evaluation structures after fire accidents were conducted by some researchers in Indonesia, which are Sulendra and Tatong [1], Rizal [2], Darmawan [3] and Wior et al. [4]. Sulendra and Tatong study the analysis of reinforced concrete material after a fire accident and the repair method for the structural element. Rizal study about strength evaluation and repair methods of building after the fire accident. Darmawan study about the structural evaluation of a market building in Madiun after a fire accident. Wior et al. studied about compressive strength of concrete and the tensile strength of reinforced concrete bars in the building of architecture and electro of the University of Samratulangi in Manado after a fire accident.

***Corresponding Author | Tri Handayani|✉ trihandayani77@gmail.com**

This study was conducted because there was a fire accident in the foundation structure consisting of a heater. The foundation structure consists of a concrete pedestal column. This study aims to find out the condition of the pedestal column structure due to a fire accident.

METHODS

The object of this study is a pedestal column foundation of the heater structure after a fire accident that has a lot of damage to its structure, including the pedestal column foundation.

The damage to concrete structures due to fire accidents is categorized into four categories which are light, medium, heavy and very heavy damage. The light damage category is included spalling of concrete cover or plaster and colour changing of a concrete surface into black and crack in the concrete surface. Medium damage is included a small crack with a depth of less than 1 mm at the concrete surface. The small cracks could be in the form of a short line with a spread pattern. This crack is caused by the concrete shrinkage process due to fire. Crack with categories as heavy damage have a bigger size and deeper. These cracks can occur in single or groups of cracks. A combination of crack and deflection is sometimes seen in the beam. Concrete spalling by exposing the reinforced concrete bar is an example of very heavy damage to concrete. Even sometimes, the reinforced concrete bar is bent or broken, and the concrete core is destroyed [5].

According to Tjokrodimulyo (2000), if cement paste or concrete is heated from room temperature until 200°C, the strength seems to increase because the free water and trapped water in cement paste evaporated when heated up to 100°C. When the temperature is increased from 400 to 600°C, hydroxide calcium ($Ca(OH)_2$) turns the composition into oxide calcium (CaO); in this condition, the concrete has no strength. And when the temperature is increased up to 600 or 700°C, other hydration result elements turned the composition, and the concrete loses its strength [6].

The study of concrete degradation at various temperatures was conducted by several researchers, which are Suhendro (2000) [3], Abrams (1979) and Schneider et al. (1989). The Results of their study are presented in **Table 1** and **Figure 1**, and **Figure 2** [7].

Table 1. Percentage of concrete property material after experiencing fire [Schneider, 1989] [7].

Temperature	200	300	400	500	600	800	1000
Compressive strength (%)	80	70	60	40	20	20	0
Modulus of elasticity (%)	60	50	40	30	10	5	0

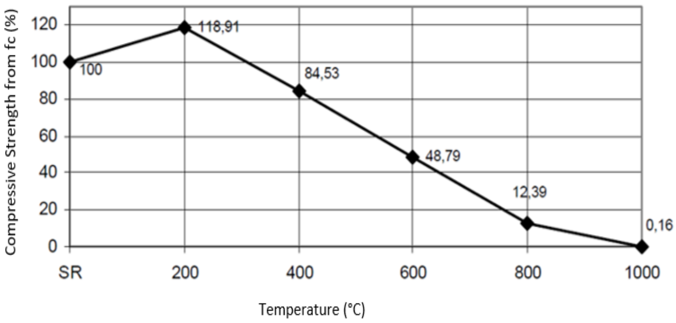

Figure 1. Degradation of concrete compression strength at various temperatures [Suhendro, 2000] [7].

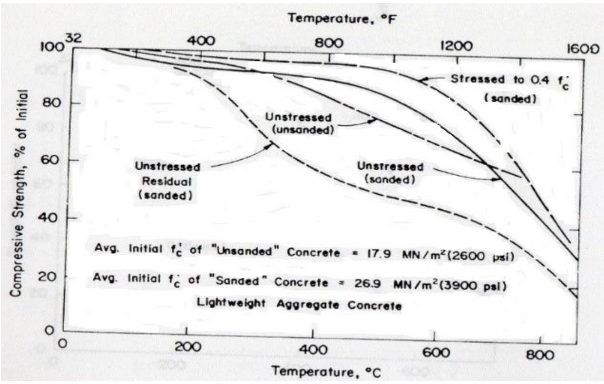

Figure 2. Degradation of concrete compression strength at various temperatures [Abrams, 1979] [7].

The structure or component of the structure still complies with the strength requirement if the required strength lower than or at least the same as the design strength. This strength is calculated by the working design load, which are dead load, live load, wind load, earthquake load and special load. The strength calculation is based on formula 1 [8].

$$R_u \leq ØR_n \quad (1)$$

With R_n is design strength, R_u is the required strength or internal force due to working load, which are moment, axial load, shear load and torque, and $Ø$ is the reduction strength factor. The structure shall have the strength to receive all required combination loads presented below in formulas 2 to 7. This combination load is used in strength analysis with the software of SAP 2000. [9], [10].

$$1{,}4\,D \quad (2)$$
$$1{,}2D + 1{,}6L + 0{,}5\,(Lr \text{ or } R) \quad (3)$$
$$1{,}2D + 1{,}6L\,(Lr \text{ or } R) + (1Lr \text{ or } 0{,}8W) \quad (4)$$
$$1{,}2D + 1{,}0W + 1{,}0L + 0{,}5\,(Lr \text{ or } R) \quad (5)$$
$$1{,}2D + 1{,}0E + 1{,}0L \quad (6)$$
$$0{,}9D + (1{,}0W \text{ or } 1{,}0E) \quad (7)$$

Where *D* is dead load, *L* is live load, *W* is wind load, *E* is earthquake load, *R* is rain load, and *Lr* is a live load on the roof or other related moment and load.

The general procedure for the strength evaluation of existing structures with the analytical method is presented in **Figure 3** [11].

Simplification of modelling is needed in the strength evaluation process. Some assumption is applicable in modelling to solve the problem easier but still accommodate or comply with the real condition. In this study, the column pedestal can be modelled as a beam element, as presented in **Figure 4**, with the joint modelled as a continuous joint or fixed joint. The system of structure is modelled in three dimensional, and the support is modelled as a pin joint [12].

The structural evaluation of the pedestal column foundation is conducted by the analytical method, which includes collecting primary and secondary data, analyzing test results, structural modelling, calculating the design strength of the pedestal column, analyzing the strength of the structure and determining the repaired method.

The equipment used in this research is Digischmidt Hammer 2000 and PUNDIT. Digischmidt Hammer 2000 is a tool to estimate the concrete strength by determining the rebound number indicating the quality/hardness of surface concrete. PUNDIT is a tool to determine the strength or quality of concrete through Ultrasonic Pulse Velocity (UPV) measurement.

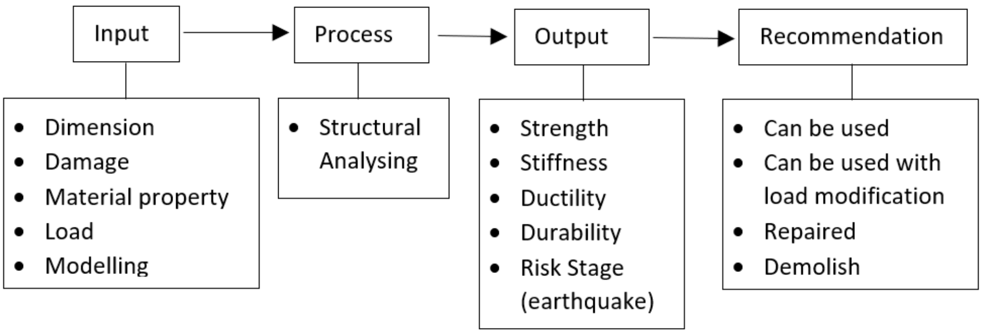

Figure 3. Strength evaluation procedure by analytical method [9].

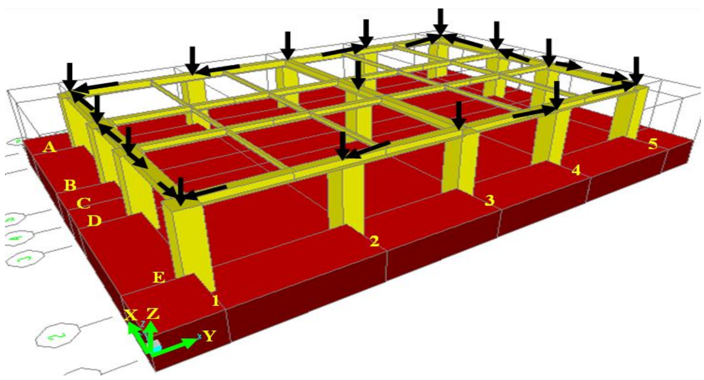

Figure 4. Modelling of pedestal column foundation of heater structure.

PUNDIT also can be used to estimate the depth of cracks in concrete. The test using the Digischmidt Hammer 2000 refers to ASTM C 805 [13], and the test using PUNDIT refers to ASTM C 597 [14].

The hammer test is conducted on all of the pedestal column structures, which are 15 pedestal columns and 10 locations in the floor slab. The UPV test has the same location as the hammer test. The depth crack measurement is conducted on the pedestal column of E2, and the measurement is from the west and south sides of the column.

RESULTS AND DISCUSSION

Research Results

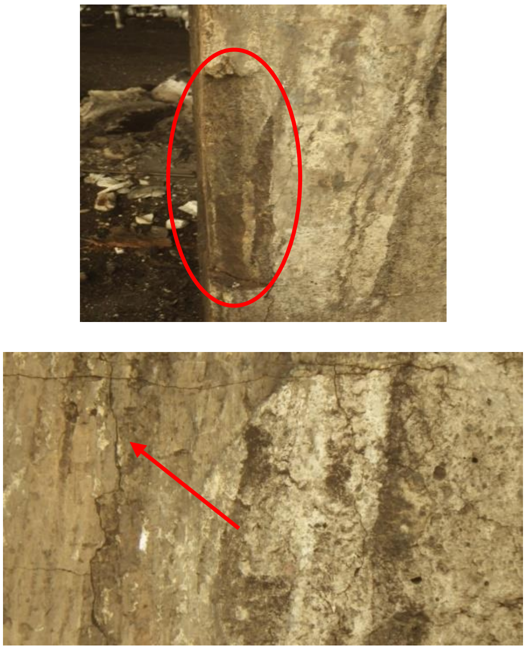

Figure 5. Spalling and crack at column E2.

Figure 6. Crack at column A2.

Crack, spalling and break out are the type of damage that occurred on the pedestal column foundation structure due to a fire accident. A large number of cracks occur on the pedestal column of E2. Concrete damage on the pedestal column of E2 is presented in **Figure 5**. Results of concrete strength inspection with hammer test and UPV test are presented in **Table 2.**

Table 2. Concrete strength inspection results.

Location	Concrete strength estimation (MPa)	
	Hammer Test	UPV Test
Column A1	21.3	19.8
Column A2	20.5	19.7
Column A3	21.5	18.4
Column A4	22.5	18.9
Column A5	21.9	21.5
Column B1	20.8	18.0
Column B5	20.0	20.4
Column C3	21.8	17.3
Column D1	21.8	21.7
Column D5	20.5	18.0
Column E1	20.8	19.5
Column E2	16.1	18.5
Column E3	20.8	18.6
Column E4	20.6	18.3
Column E5	21.4	21.3
Slab P1	19.1	48.4
Slab P2	16.5	45.5
Slab P3	15.8	35.2
Slab P4	18.3	42.7
Slab P5	18.1	40.6
Slab P6	21.4	39.6
Slab P7	17.8	33.0
Slab P8	16.3	37.0
Slab P9	16.5	28.5
Slab P10	19.8	18.0

Table 3. Percentage of concrete strength results.

Component	Concrete specification (MPa)		
	100%	85%	75%
Column	20	17	15
Slab	20	17	15

Figure 7. Crack at column E1.

Results of crack depth measurement on pedestal column foundation E2 are presented in Table 4 and Table 5

Table 4. Results of crack depth measurement of pedestal column foundation E2 (west side).

Structure: Column E2 from the west side					
Elevation (mm)	Distance (mm)		Transit Time (s)		Crack Depth (mm)
S	X_1	X_2	T_1	T_2	D
830	150	300	57.3	103.8	42.08
1220	150	300	66.4	113.8	55.55
1440	150	300	55.8	102.8	37.73
1640	150	300	57.0	92.5	68.60

Table 5. Results of crack depth measurement of pedestal column foundation E2 (south side).

Structure: Column E2 from the south side					
Elevation (mm)	Distance (mm)		Transit Time (s)		Crack Depth (mm)
S	X_1	X_2	T_1	T_2	D
1010	150	300	95.3	156.4	65.88
1240	150	300	89.6	148.5	63.52
1420	150	300	46.4	88.7	27.06
1610	150	300	59.3	96.6	67.67

Table 6. The required strength of pedestal column foundation A_1 – C_3.

Load Type	The required strength of the pedestal column (tonnes)							
	N	A_1	A_2	A_3	A_4	A_5	B_1	B_5	C_3
Dead load	N_z	54.10	33.22	33.84	33.22	54.10	86.50	86.50	28.36
	H_x	-2.14	-	-	-	-2.14	-1.85	-1.85	-
	H_y	-0.65	-1.40	-	1.40	0.65	-	-	-
Transverse wind	N_z	-19.50	-	-	-	-19.5	-6.11	-6.11	-
	H_x	3.27	0.44	0.42	0.44	3.27	4.16	4.16	-
Longitudinal wind	N_z	-4.08	-0.86	0.11	1.01	3.82	-	-	-
	H_y	1.35	1.94	1.81	1.83	0.95	0.34	0.17	-
Transverse earthquake	N_z	18.07	0.44	0.45	0.44	18.07	7.42	7.42	-
	H_x	2.90	1.83	1.86	1.83	2.98	4.76	4.76	-
Longitudinal earthquake	N_z	9.72	0.84	-	0.84	9.72	1.30	1.30	-
	H_y	2.76	1.69	-	1.69	2.76	4.41	4.41	-

Table 7. The required strength of pedestal column foundation D_1 – E_5.

Load Type	The required strength of the pedestal column (tonnes)							
	N	D_1	D_5	E_1	E_2	E_3	E_4	E_5
Dead load	N_z	86.50	86.50	33.84	33.32	54.10	86.50	86.50
	H_x	1.85	1.85	-	-	-2.14	-1.85	-1.85
	H_y	-	-	-	1.40	0.65	-	-
Transverse wind	N_z	6.91	6.91	-	-	19.50	-6.11	-6.11
	H_x	4.19	4.19	0.42	0.44	3.27	4.16	4.16
	N_z	-	-	0.11	1.01	3.82	-	-

Longitudinal wind	H_y	0.34	0.17	1.81	1.83	0.95	0.17	0.17
Transverse earthquake	N_z	7.42	0.44	0.45	0.44	18.07	7.42	7.42
	H_x	4.76	1.83	1.86	1.83	2.98	4.76	4.76
Longitudinal earthquake	N_z	1.30	0.84	-	0.84	9.72	1.30	1.30
	H_y	4.41	1.69	-	1.69	2.76	4.41	4.41

Discussions

Crack and spalling on concrete may occur after a fire with temperatures up to 200°C because there is compression in the empty pores that causes crack and spalling on concrete. This condition may occur on pedestal columns E1 and A2 (see **Figure 6** and **Figure 7**).

Damage or failure that occurred on pedestal column E1 is a type of broken failure or concrete breakout. This type of failure is caused by a shear load at anchorage support (see **Figure 8**). Based on SNI 2847:2013 standard about the requirement of Structural Concrete for Building mentioned that a structure or component of a structure is in a safe condition if the required strength is below or at least the same as the design strength.

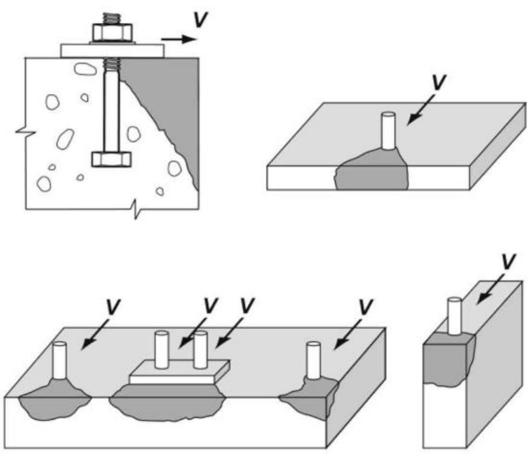

Figure 8. Type of damage in concrete due to shear load at anchorage support.

Refer to results of structural analysis by finite element calculation with SAP 2000 software obtained the required strength of pedestal column foundation as presented in **Table 6** and **Table 7**. After obtaining the required strength of each pedestal column foundation, the next step is comparing the required strength with the design strength of each pedestal column foundation according to the cross-section data of the pedestal column as described in **Table 8**.

Calculation of the cross-sectional capacity of the pedestal column is done by inputting the value of existing compressive strength results of concrete data. Data on concrete compressive strength used to calculate the cross-sectional capacity of the pedestal column foundation is presented in **Table 8**.

The value of the required strength and design strength of the column is determined by plotting a di interaction diagram between the Nominal load value (P_n) and Nominal Moment value (M_n). If the required strength value is inside of the interaction diagram of design strength, then the column is safe to carry the operational load. But if the required strength value is outside of the design strength interaction diagram, then the column is unsafe for carrying the operational load. Calculation results of the cross-sectional capacity of column (design strength) described the interaction diagram between nominal load (P_n) and nominal moment (M_n) as presented in **Figure 9** for pedestal column foundation C3 and calculation results for other pedestal columns are presented in **Table 9**.

Table 8. Cross section and concrete strength of pedestal column.

Pedestal code	Dimension (mm)		Longitudinal Bar		Shear Bar	Concrete Strength (MPa)
	b	h	Axis X	Axis Y		
A1	600	600	4Ø22	4Ø22	Ø10-200	19.75
A2	600	600	4Ø22	4Ø22	Ø10-200	19.67
A3	600	600	4Ø22	4Ø22	Ø10-200	18.43
A4	600	600	4Ø22	4Ø22	Ø10-200	18.92
A5	600	600	4Ø22	4Ø22	Ø10-200	21.50
B1	600	600	4Ø22	4Ø22	Ø10-200	18.01
B5	600	600	4Ø22	4Ø22	Ø10-200	20.42

C3	600	600	4Ø22	4Ø22	Ø10-200	17.35
D1	600	600	4Ø22	4Ø22	Ø10-200	21.75
D5	600	600	4Ø22	4Ø22	Ø10-200	18.01
E1	600	600	4Ø22	4Ø22	Ø10-200	19.51
E2	600	600	4Ø22	4Ø22	Ø10-200	18.51
E3	600	600	4Ø22	4Ø22	Ø10-200	18.59
E4	600	600	4Ø22	4Ø22	Ø10-200	18.34
E5	600	600	4Ø22	4Ø22	Ø10-200	21.33

Table 9. P_u and M_u in the interaction diagram of $P_n – M_n$.

Pedestal column	Load Pu (t)	Moment Mu (t.m)	Position in curve
A1	54.10	9.07	Inside curve
A2	33.22	5.38	Inside curve
A3	33.84	5.16	Inside curve
A4	33.22	5.08	Inside curve
A5	54.10	9.07	Inside curve
B1	86.50	13.21	Inside curve
B5	86.50	13.21	Inside curve
C3	28.36	0	Inside curve
D1	86.50	13.21	Inside curve
D5	86.50	13.21	Inside curve
E1	54.10	8.46	Inside curve
E2	33.22	5.08	Inside curve
E3	33.84	5.16	Inside curve
E4	33.22	5.08	Inside curve
E5	54.10	8.46	Inside curve

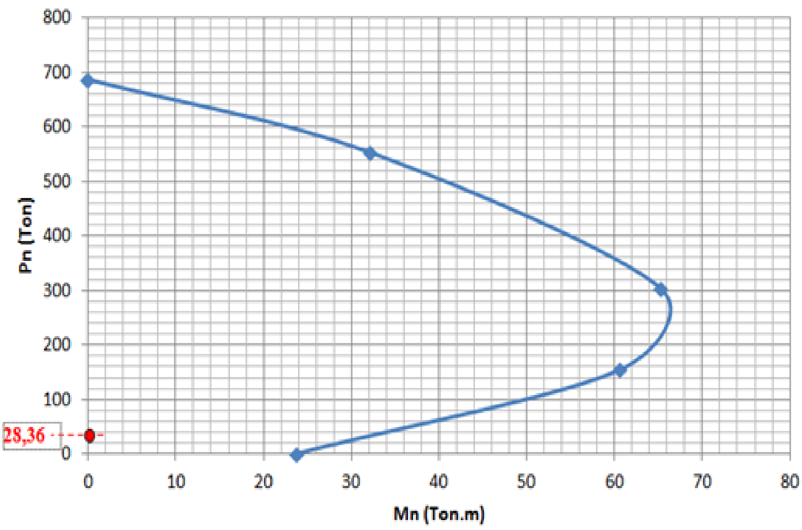

Figure 9. Interaction diagram of P – M at Pedestal Column of C3.

Based on calculation results for the pedestal column of C3, as shown in **Figure 9** and **Table 9** for all of the pedestal columns, it can be seen that all of the pedestal column foundations have the required strength value inside of the design strength interaction diagram. It means that the pedestal column foundation is safe for carrying the operational load**.**

CONCLUSION

According to data, results and discussion given, it can be concluded that the concrete compressive strength of the pedestal column foundation is still up to 85% of the concrete compressive strength specification, which indicates the concrete experienced by the fire with temperature below 300°C and with this condition, pedestal column foundation still safe for carrying its operational load.

AUTHOR INFORMATION

Corresponding Authors
E-mail: trihandayani77@gmail.com.
Phone: +62 81393684xxx
E-mail: pugu001@brin.go.id.

Author Contributions
First Author and Second Authors have contributed equally to this work.

ACKNOWLEDGEMENTS

We would like to thank our institution's National Laboratory for Structural Strength Technology (B2TKS - BPPT). B2TKS has accommodated and facilitated this research and to our colleagues in B2TKS who have helped in conducting examination and testing for this research.

REFERENCES

[1] Sulendra, I.K, Tatong, B, Analisis Material Beton Bertulang Pasca Kebakaran dan Metode Perbaikan Elemen Strukturnya, E-Journal Undip Tahun 2016 No.1, pp.48-60, http://ejournal.undip.ac.id/index.php/mkts/article/view/3665, 2008.

[2] Rizal, F., *Evaluasi Kekuatan dan Metode Perbaikan Struktur Beton pada Gedung Pasca Kebakaran*, jurnal Portal Vol 2 No.2 ISSN 2085-7454. http://jurnal.pnl.ac.id/?p=892, 2008.

[3] Darmawan, S., *Evaluasi Struktur Bangunan Pasar di Madiun Pasca Kebakaran*, Seminar Nasional Aplikasi Teknologi Prasarana Wilayah ISSN 2085-7454. http://jurnal.pnl.ac.id/?p=892, 2010.

[4] Wior, C.E., Wallah, S.E., Pandaleke, R.: *Kajian Kuat Tekan Beton dan Kuat Tarik Baja Tulangan Gedung Teknik Arsitektur dan Elektro Universitas Sam Ratulangi Manado Pasca Kebakaran*, Jurnal Sipil Statik, vol. 3 No.4 April 2015, http://ejournal.unsrat.ac.id/index.php/jss/article/view/8208/7767, Manado, 2015.

[5] Departemen Pekerjaan Umum, Pd-T-08-2004-C, Pedoman Pemeriksaan Konstruksi Bangunan Beton Bertulang Pasca Terbakar, Bandung, 2007.

[6] Tjokrodimulyo, K, Pengujian Mekanik Laboratorium Beton Pasca Bakar, PAU Ilmu Teknik Universitas Gadjah Mada, Yogyakarta, 2000.

[7] Suhendro, B., *Analisis Degradasi Kekuatan Struktur Beton Bertulang Pasca kebakaran*, PAU Ilmu Teknik Universitas Gadjah Mada, Yogyakarta, 2000.

[8] Badan Standarisasi Nasional, SNI 2847:2020, Persyaratan Beton Struktural untuk Bangunan Gedung, Jakarta,2020.

[9] Badan Standarisasi Nasional, SNI 1727:2020, Beban Minimum untuk Prencanaan Bangunan Gedung dan Struktur Lain, Jakarta,2020.

[10] Badan Standarisasi Nasional, SNI 1726:2019, Tata Cara Prencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan Non Gedung, Jakarta,2019.

[11] Triwiyono, A, Evaluasi dan Rehabilitasi Bangunan Gedung, Magister Pengelolaan Sarana dan Prasarana Universitas Gadjah Mada, Yogyakarta, 2009.

[12] Triwiyono, A, Evaluasi dan Rehabilitasi Bangunan Jalan dan Jembatan, Magister Pengelolaan Sarana dan Prasarana Universitas Gadjah Mada, Yogyakarta, 2009.

[13] ASTM.: *ASTM C805 Standard Test Method for Rebound Number of Hardened Concrete*, ASTM International, Wes Conshohocken USA, 2018.

[14] ASTM.: *ASTM C597 Standard Test Method for Pulse Velocity Through Concrete*, ASTM International, Wes Conshohocken USA, 2016.