

Assessment and evaluation procedure of existing industrial building structure based on ASCE 41-17

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Abstract. Both the building structure and infrastructure in Indonesia today has increased in line with the development of planning and design regulations. Learning from the past, the concept of planning and design continues to be improved to ensure the safety of the surrounding environment. The completed building needs to be evaluated for the development of the existing structure. In terms of examining the quality of the material on the existing structural elements, a test is divided into two types, namely destructive and non-destructive. In concrete destructive test was done by coring tests while for non-destructive test the Ultrasonic Pulse Velocity (UPV) test method was used, Brinell Hardness test was used in steel. In this case industrial building were built in the 1990s. The workflow refers to ASCE 41-17 including examining existing buildings which are divided into three tiers namely Tier 1: Screening, Tier 2: Deficiency-Based Evaluation and Retrofits, Tier 3: Systematic Evaluation and Retrofits. In this paper was limited only in tier 1. From the results in both the ASD and LRFD methods obtained data that some steel members that were reviewed need to be carried out further analysis at tier-2 level where It was needed to do retrofit.

1. Introduction

The development of structures and infrastructure in Indonesia today continues to be conducted and improved in an effort to pursue technological developments and support the economy. Starting from the construction of road infrastructure, bridges, communication networks and electricity to the structure of buildings, industrial zones, factories and many more. In some cases, many buildings that were completed several decades ago are still used effectively today. This condition needs to be considered because the building has life expectancy which will be impacted by the quality of supporting material [1].

Over time, not only the construction work continues to grow, but regulations are also regularly updated. Learning from cases that occur in the construction world, design code is constantly being reviewed and updated to ensure human security from disasters. in developed countries like the United States, regulatory and technological updates are very fast. It can be seen in the AISC, which since its first issuance of the ASD design method in 1927 which has been proven reliable but continues to update the regulations until the last one was revised in June 2019. The relatively simple ASD design method is



preferred by practitioners in the application of planning which makes this method popular. This relatively conventional method has the same safety factor and is practical to use. AISC recognizes the need for other design methods that have more reliable safety factors so the LRFD design method was introduced in 1991. This method takes into account not only the yield stress (f_y) or critical stress (f_{cr}) but also the inelastic behavior that might occur such as the formation of a plastic section (M_p) on a section with compact criteria or the tensile strength of the material in the connection which can maintain the structural ductility [2].

Examination of existing buildings according to ASCE 41-17 can be divided into three levels of work, namely; Tier 1: Screening, Tier 2: Deficiency-Based Evaluation and Retrofits, Tier 3: Systematic Evaluation and Retrofits. Each tier in terms of ASCE 41-17 is a stage of evaluating existing buildings where the higher the tier, the more advanced the analysis will be. In tier 1, it is expected that relevant information about the building performance level, seismic capacity that can be building could withstand and building description in general can be obtained through a brief inspection. The results of this short inspection are then used to calculate the stiffness and strength of building components to be a reference to determine whether the building is in accordance with the evaluation criteria that are required or not [3].

In this paper we will discuss building assessment work regarding to ASCE 41-17 and for structural analysis refer to the AISC 360-10 ASD and LRFD methods. The quality of structural elements is obtained by examining NDT or destructive test (DT). NDT is the process of inspection, testing, or evaluation of materials without damaging the components being tested. In other words, when the inspection or test is complete the tested part can still be used unlike the DT which after the testing process the tested part can no longer be used or damaged [9]. In this study the age of the building which has been 20 years and the existence of regulatory updates are the main causes of this assessment work. The building to be studied located in Tangerang, a one-story warehouse with 42 meters length 46 meters width and height of 8.8 meters. The structure that functions as an industrial building holds a load of 1000 kg/m^2 on the ground floor and 400 kg/m^2 on the mezzanine.

2. Literature Review

2.1. Destructive and Non-Destructive test Method

Concrete is a construction material that is widely known and used on a wide scale. It is an important reason to understand the crack mechanism. Many studies mention that concrete is a homogenous material if reviewed macroscopically. This assumption often results in inaccurate predictions about crack patterns and load capacities that can be borne because concrete is a heterogenous material. In mesoscale, concrete is made of four phases: coarse aggregate, air space, cement paste and the interface transition zone (ITZ), which is between coarse aggregate and cement paste [4].

Many structural regulations and technical recommendations indicate that the strength of concrete in situ must be estimated from the average value of the coring test which is accompanied by a non-destructive test. With non-destructive testing the number of coring test will be significantly reduced in an effort to estimate the overall strength of concrete [5]. Coring test method that is direct and conventional has the potential to cause risks in the process if it is not executed carefully in determining the coring point. In the non-destructive method the condition of the concrete relatively does not provide physical impacts such as coring. In terms of the duration of processing time it can be said that the NDT test is much faster and more practical.

The NDT method commonly used is Ultrasonic Pulse Velocity (UPV). Recommendations regarding this testing method are available on several standards such as [6]. A complete overview of this method can be displayed on [7].

2.2. Evaluation Based on ASCE 41-17

The evaluation method used in this paper is ASCE 41-17. In this regulation there are design criteria that include evaluation systems for both seismic and reinforcement of all types of buildings. The concrete structure evaluated in ACI 369.1M-17 consists of part of the contents of a chapter in ASCE 41-17. In

chapter 10, it can be found that regulations related to the evaluation of concrete buildings ranging from material characteristics, test object collection standards, building moment bearing frame systems, concrete reinforcement joints, to precast systems and acceptance standards in each evaluation system [8].

Broadly speaking, the seismic evaluation method for concrete structures is divided into three levels namely; Tier 1 briefly discusses evaluation procedures that can be used by structural engineer to provide an initial overview of building conditions. The intended initial description is expected to provide data related to building performance with a simple level of analysis with only reference to elastic limits. If there is no seismic activity with a large magnitude, the engineer can determine the level of the disaster to be used as a reference calculation. Engineer are also expected to be able to determine the priority level of the building based on the function, size and even historically. This level of virtue will have an impact on the level of building evaluation limits, the more important the building design criteria will also be more stringent.

At the second level, Tier 2, deficiencies in Tier 1 analysis results will be evaluated. It could be said that Tier 2 is an advanced level of Tier 1. If on Tier 1 evaluation still found any deficiencies but still considered in a relatively acceptable condition then the evaluation is finish at this level. Conversely, if deficiencies found in Tier 1 result in unacceptable results according to Tier 2 design criteria, then these deficiencies must be addressed. Tier 2 treatments can be found in the parenthesis of every checklist in Tier 1. At the highest level, which is Tier 3, a nonlinear structural analysis will be conducted where the behavior of the existing buildings obtained at tier 1 will be re-evaluated with the influence of the results of tier 2. If the tier 1 analysis found that there are deficiencies in the design criteria, improvements will be made if the functions, loading and behavior are the same as the initial planning so the building only needs to be restored according to the original function. If a deficiency occurs in an existing building and this building needs to be increased its capacity will be strengthened in the form of adding structural elements to the part that is deemed necessary.

Whereas in this tier 3 the results of the retrofits in tier 2 will be evaluated in a structural system by reviewing the strength, ductility and performance of the designed force with the influence of the previous retrofits. Performance-based system planning will be done at tier 3 in the form of non-linear analysis such as pushover or time history. The results of both types of analysis will provide a very accurate result of the impact of structural reinforcement by reviewing up to the level of performance of a building. Since the time and resources used to conduct this Tier 3 Analysis are relatively high, it is likely that only buildings with a high degree of priority and importance will be analyzed using Tier 3. Buildings that have been analyzed at this level can be a benchmark for other buildings in conducting Tier 1 and 2 analysis.

2.3. Analysis of Existing Structures Based on SNI 1729: 2015

The imposed load on the ground floor will be assumed to be held directly by the ground using the slab on grade method which is generally used in warehouse structure. The load on the mezzanine floor is theoretically permitted to be reduced if it is less than 500 kg/m² in accordance with SNI 1727: 2013 article 4.7.2 which covers the reduction of uniform loads (Eq 2.1) [9].

$$L = L_o \left(0.25 + \frac{4.57}{\sqrt{K_{LL} A_T}} \right) \quad (1)$$

Basically SNI 1729 is an absorption of AISC 360-10 so the calculation procedure is the same as the metric version of the code [2]. To get the member strength, it is required load resistance and factored design (DFBK) or in the terminology AISC is known as a method Load Resistance and Factored Design (LRFD) can be seen in (Eq 2.2). Whereas to obtain the allowable strength it required an allowable strength design (DKI) method or Allowable Strength Design (ASD) can be seen in (Eq 2.3) [10]. Explanation of the series of design methods for calculating R_n values can be seen in SNI 1729: 2015 chapters D to F or in AISC 360-10 chapters D through H [11].

$$R_u \leq \phi R_n \quad (2)$$

$$R_u \leq \frac{R_n}{\Omega} \tag{3}$$

2.4. Research Limitation

This paper is limited in several aspect as shown below:

- a. The destructive method reviewed in the concrete quality test is the coring test
- b. The non-destructive method reviewed in the concrete quality test is the UPV test
- c. The non-destructive method reviewed in the steel quality test is the Brinell Hardness test
- d. Concrete quality test results are reviewed up to their correlation using linear regression
- e. Structural evaluations limited to be only up to Tier 1.
- f. The structural elements evaluated are in the steel beam section.

3. Research Methodology

In this study concrete material were evaluated by using destructive and non-destructive methods test. Tests performed are coring tests for destructive methods and UPV tests for non-destructive methods. The results obtained in the coring test are concrete compressive strength in MPa. The coring result from the laboratory test continued to be check using standard deviation as the indicator. After the standard deviation is obtained then it is continued to check the relative standard deviation. If the result is satisfied, then it is analyzed using linear regression method. The regression would compare the compressive strength toward number of samples in order to obtain goodness level of data set.

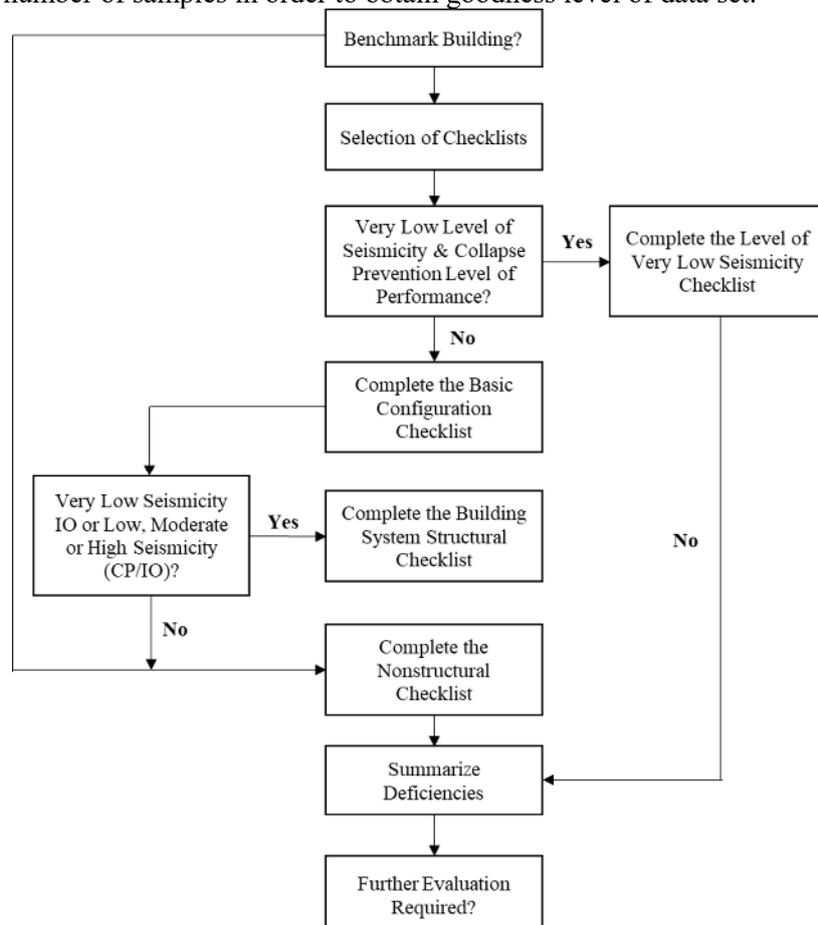


Figure 1. Work flow of tier-1 ASCE 41-17 [3]

In the non-destructive test using UPV method, data of velocity is obtained to become reference to determine the condition of concrete. UPV test also produce data of concrete grade. Therefore, the correlation that performed would be between concrete conditions and concrete grade. Both of the result being identified of its standard deviation value to know the data distributions. If the distributions are in

a good category then the linear regression analysis is performed again to know the correlation between concrete grade and its number of samples. If the result of regression analysis is good it is mean that the data is satisfy goodness level and then the average concrete grade could be taken to investigate the existing concrete capacity.

Brinell hardness test is the testing method that used in this paper in order to identify the steel quality on the location that being observed. The results of this test are in the form of hardness level and steel quality. The result data will be examined by its relative standard deviation value in order to determine the reliability data based on its distribution. If the results are acceptable, then these two results will be analyzed using linear regression method to find out its correlation. If the result of regression analysis satisfy is fulfill the goodness level then the results of this regression if satisfactory and the average quality of steel quality is taken to be used as a reference to determine the steel profile capacity.

The results of the concrete grade regression are displayed in a separate table with steel grade. The results of the steel grade are used to determine the steel profile nominal capacity. The steel profile will be analyzed by using both ASD and LRFD design provisions according to AISC 360-10. The steel ratio as the result of analysis then tabulated and the output of Tier-1 analysis is presented in the conclusions section.

4. Results and Discussion

In the coring test, 9 samples were placed randomly taken at a certain point. The coring data can be seen in table 1.

Table 1. Coring test result

| No | MPa |
|----|-------|
| 1 | 22.22 |
| 2 | 15.14 |
| 3 | 22.78 |
| 4 | 12.98 |
| 5 | 12.6 |
| 6 | 21.9 |
| 7 | 20.45 |
| 8 | 26.81 |
| 9 | 22.97 |

From the above data, the average value of concrete quality is 19.76 MPa. This value is spread over each structural element with a standard deviation value of 4.985 and has a relative standard deviation value of 0.25227. The tabulated values above can be seen in table 2.

Table 2. Core drill test result analysis

| DESCRIPTION | RESULTS |
|-------------|-----------|
| AVG | 19.76 MPa |
| SD | 4.99 |
| RSD | 0.25 |

In the UPV Test, two data variants are obtained, namely fast wave velocity and concrete quality. The velocity value below is a parameter to assess the density of concrete based on the speed of the sensor in passing through the material. If it is less than 3000 m/s, it is categorized that the concrete is in poor condition or behaves badly. From the UPV Test data obtained the average value for velocity is 3504.75 m/s which states that the condition of the concrete material is in relatively good condition. With a standard deviation value of 418.92 and a relative standard deviation value of 0.12 it can be said that this

data has a good variant. As for the concrete quality, the value is 25.67 MPa with a standard deviation of 4.37 and a relative standard deviation of 0.17. it can be concluded that the data has good variants. Concrete velocity and quality data with a total sample of 100 that have been confirmed for reliability are then correlated with regression analysis which results in an R^2 of 0.9913 as shown in the Table 3 below.

Table 3. UPV Test result

| UPV TEST (Velocity) | | UPV TEST (Grade) | |
|---------------------|-------------|------------------|--------|
| AVG | 3504.75 m/s | 25.67 | MPa |
| SD | 418.92 | 4.37 | |
| RSD | 0.12 | 0.17 | |
| Regression Analysis | | R^2 | 0.9913 |

In the Brinell Hardness test, two data variants were found, namely hardness level and steel quality. The average value of hardness level obtained is 257, each hardness level value will be converted into MPa units and if seen from Table 4 will have 211.75 MPa results. With a standard deviation of 57.24 and an effective standard deviation value of 0.22 this data can be expressed in a good variant so that it can be used for regression analysis together with its tensile strength value which has a standard deviation of 96 and a relative standard deviation of 0.45. Brinell hardness and steel quality data with a total sample of 50 has an R^2 value of 0.982615 as shown in Table 4.

Table 4. Brinell Hardness Test

| BRINELL (Hardness Level) | | BRINELL (Steel Grade) | |
|--------------------------|--------|-----------------------|------------|
| AVG | 257.00 | AVG | 211.75 MPa |
| SD | 57.24 | SD | 96.00 |
| RSD | 0.22 | RSD | 0.45 |
| Regression Analysis | | R^2 | 0.982615 |

The imposed load of the machine on the mezzanine floor of the building under review is 400 kg/m² and then reduced according to the area of tributary. From this load we get the internal forces acting on the steel profile that being reviewed which can be seen in Table 5.

Table 5. Forces result in steel beam

| No | Code | Steel Profile | Axial | Moment | | Shear |
|----|------|-----------------|--------|--------|--------|--------|
| | | | | Major | Minor | |
| | | | | Ton | Ton-m | |
| 1 | B1 | WF 350X175X7X11 | 0.315 | 6.4 | 0.0004 | 4.875 |
| 2 | B1 | WF 350X175X7X12 | 0.253 | 18.2 | 0.0003 | 14.3 |
| 3 | B1 | WF 350X175X7X13 | 0.244 | 7.3 | 0.0001 | 5.43 |
| 4 | B1 | WF 350X175X7X14 | 0.236 | 19.764 | 0.0001 | 14.76 |
| 5 | B1 | WF 350X175X7X15 | 0.234 | 5.53 | 0.0001 | 4.63 |
| 6 | B1 | WF 350X175X7X16 | 0.246 | 15.343 | 0.0001 | 12.71 |
| 7 | B2 | WF 250X125X6X9 | 0.0278 | 2.7662 | 0.0001 | 2.966 |
| 8 | B2 | WF 250X125X6X9 | 0.03 | 6.076 | 0.0001 | 6.0332 |

From the design forces on table 5 then the analysis proceeds into determination of its nominal capacity. There are two design provision that used in this analysis; ASD and LRFD. The ASD design provision used as an initial analysis since it has a relatively larger safety factor compare top LRFD. However, since the load of machine act on top of the steel member was already installed without any changes on its function, it is recommended to use LRFD method which has relatively smaller safety factor and shows close to its actual condition. The calculation result of ASD and LRFD design provision are shown below in Table 6 and Table 7 respectively.

Table 6. Nominal capacity using ASD method

| No | Code | Steel Profile | AISC LRFD 360-10 | | | |
|----|------|-----------------|------------------|------------|-------|------------|
| | | | ϕP_n | ϕM_n | | ϕV_n |
| | | | | Major | Minor | |
| | | | | Ton | Ton-m | |
| 1 | B1 | WF 350X175X7X11 | 120.33 | 16.02 | 3.29 | 29.171 |
| 2 | B1 | WF 350X175X7X11 | 120.33 | 16.02 | 3.29 | 29.171 |
| 3 | B1 | WF 350X175X7X11 | 120.33 | 16.02 | 3.29 | 29.171 |
| 4 | B1 | WF 350X175X7X11 | 120.33 | 16.02 | 3.29 | 29.171 |
| 5 | B1 | WF 350X175X7X11 | 120.33 | 16.02 | 3.29 | 29.171 |
| 6 | B1 | WF 350X175X7X11 | 120.33 | 16.02 | 3.29 | 29.171 |
| 7 | B2 | WF 250X125X6X9 | 79.74 | 6.71 | 1.38 | 17.685 |
| 8 | B2 | WF 250X125X6X9 | 79.74 | 6.71 | 1.38 | 17.685 |

Table 7. Nominal capacity using LRFD method

| No | Code | Steel Profile | AISC ASD 360-10 | | | |
|----|------|-----------------|-----------------|----------------|-------|----------------|
| | | | P_n / Ω | F _b | | V_n / Ω |
| | | | | Major | Minor | |
| | | | | Ton | Ton-m | |
| 1 | B1 | WF 350X175X7X11 | 80.06 | 13.78 | 19.56 | 43.765 |
| 2 | B1 | WF 350X175X7X11 | 80.06 | 13.78 | 19.56 | 43.765 |
| 3 | B1 | WF 350X175X7X11 | 80.06 | 13.78 | 19.56 | 43.765 |
| 4 | B1 | WF 350X175X7X11 | 80.06 | 13.78 | 19.56 | 43.765 |
| 5 | B1 | WF 350X175X7X11 | 80.06 | 13.78 | 19.56 | 43.765 |
| 6 | B1 | WF 350X175X7X11 | 80.06 | 13.78 | 19.56 | 43.765 |
| 7 | B2 | WF 250X125X6X9 | 47.75 | 13.8 | 19.57 | 26.53 |
| 8 | B2 | WF 250X125X6X9 | 47.75 | 13.8 | 19.57 | 26.53 |

After obtaining the nominal capacity of the profile, then the internal force obtained in Table 5 is divided by the capacity of each planning code to get the member ratio. The steel profile ratio is shown in table 8.

Table 8. Nominal capacity using LRFD method

| No | Code | Steel Ratio | | Differences % |
|----|------|-----------------|------------------|------------------|
| | | AISC ASD 360-10 | AISC LRFD 360-10 | |
| 1 | B1 | 0.663 | 0.441 | 33.5 |
| 2 | B1 | 1.76 | 1.177 | 33.1 |
| 3 | B1 | 0.75 | 0.497 | 33.7 |
| 4 | B1 | 1.92 | 1.275 | 33.6 |
| 5 | B1 | 0.58 | 0.387 | 33.3 |
| 6 | B1 | 1.5 | 0.999 | 33.4 |
| 7 | B2 | 0.76 | 0.48 | 36.8 |
| 8 | B2 | 1.42 | 0.976 | 31.3 |

5. Conclusion and Recommendation

ASCE 41-17 tier 1 can be used as initial, fast and basic assessment to determine damage of existing building due to earthquake, aging, overloading, code updating and renovation. From the assessment results in both concrete and steel grade, it can be seen that there were some of grade degradation which would affect the member capacity of either the concrete or steel structure. After performing structural analysis using AISC 360-10, both ASD and LRFD shows that some of the steel member exceeds its own capacity.

Therefore, it is recommended to perform tier-2 analysis in order to provide a proper retrofitting method on the structural steel element. Performing tier-3 analysis to check the structural performance after retrofits is highly recommend in further research.

Acknowledgment

The author would like to express the gratitude towards PT. Deltakoni and related parties to support this paper so this paper could be completed and hopefully brings benefit to society especially in the world of civil engineering

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