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Structural Evaluation and Strengthening Strategy of the Law Faculty Hall Building in Andalas University, Padang, Indonesia

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***Abstract*— The Law Faculty Hall building is one of the composite steel-concrete building structures in Andalas University, Padang, Indonesia. This building was designed according to the old Indonesian seismic code (SNI 1726-2002). The building was first constructed in 2006. However, it cannot be completed in the year due to the lack of the university budget. In 2012, the revised seismic code (SNI 1726-2012) was published, so evaluating the building structure should be carried out according to the revised code. The building's analysis results based on SNI 1726-2012 show that the existing building could not carry the combination of loads acting on the building structure. Therefore, the building should be strengthened before continuing the construction to meet the new performance-based seismic design techniques' requirements. In this study, there are three strengthening methods recommended and analyzed: (a) Installment of inverted V-type steel bracing (IWF 200.100.5.5.8) to the structural frames; (b) Increase of the web thickness of the IWF beams; and (c) Addition of the longitudinal steel bar (4 D10) and shear reinforcement (Ø8-150mm) to the composite beams. The building performance is evaluated in terms of the structural elements' load-bearing capacity, story drifts, and lateral displacements. The results show that all the strengthening methods improve the building's structural capacity to resist the applied loads. Therefore, reinforcement bars to the composite beams were recommended as the best method to strengthen the building due to cost-effectiveness and ease installed.**

***Keywords*— Steel-concrete composite; earthquake load; strengthening; steel bracing; reinforcement bar.**

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I. INTRODUCTION

Steel and concrete are the most commonly used construction materials for building. These materials can be combined in a structural system, known as composite steel-concrete structure, such as Steel Reinforced Concrete (SRC), Concrete Encased Steel (CES), and Concrete Filled Tube (CFT) structures. Steel-concrete composite elements use concrete's compressive strength alongside steel's resistance to tension, and when tied together, this results in a highly efficient and lightweight unit that is commonly used for multi-story buildings [1].

The Law Faculty Hall building of Andalas University, as shown in Fig. 1, was made of a composite structure that serves as a supporting student activity, such as sport, meeting, and some ceremony. This building was first constructed in 2006 and designed using the old Indonesia seismic code (SNI 03-1726-2002) [2]. Due to the lack of the university budget, the building cannot be finished in the year. In 2012, the revised seismic code, SNI 03-1726-2012, has been published [3]. Due to the new seismic code's establishment, the existing building structure's load-carrying capacity should be evaluated by using SNI 03-1726-2012 before continuing the construction.

A survey and analysis of the existing building structures should be carried out based on the current building code to determine whether the building is strong or weak in carrying the service loads. The strengthening of the weak buildings should be done before the occurrence of the probable earthquake. Strengthening is the process of upgrading structures to improve the existing building structure's performance, especially to carry the seismic load. Building codes commonly drive the need for strengthening a building structure, deterioration, change in use, or building assessment results indicate that the strength of structural members available was insufficient to carry the service loads, especially in future quakes.

The structural building's strength is generated from the structural dimensions, shape, materials, exemplary detailing, and many structural elements [4]. In general, strengthening aims to improve the existing structure's capacity [5]. Three strengthening methods were recommended and analyzed in the hall building. Firstly, by adding the inverted V-type steel bracing on the building, second, by increasing the IWF beams' web thickness and adding the reinforcement steel bars (bending and shear reinforcement) to the composite beams.

(a) The view from inside the hall building

(b) The view from outside of the hall building

Fig. 1 Photos of existing Law Faculty Hall building of Andalas University.

II. MATERIAL AND METHOD

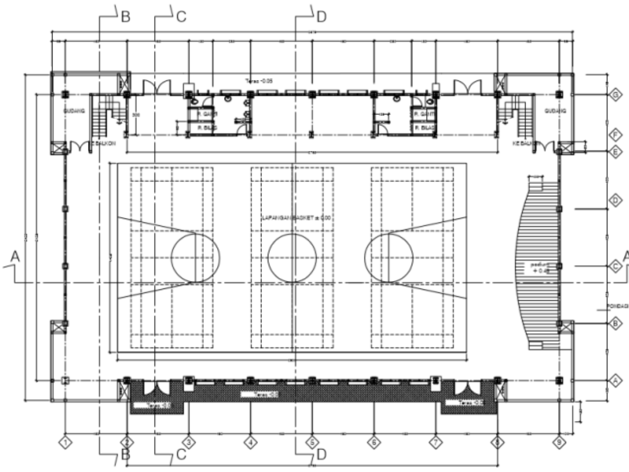
A. Data of Existing Structure

The structure evaluation is carried out according to a review of the available construction documents and visual observations. The building was designed by using a concrete-encased steel structural system with the concrete comp. strength, f'_c = 21 MPa. The composite column sizes are K1 with the dimension of 300 x 500 mm^2 using IWF 350.175.7.11 and K2 with the dimension of 250 x 400 mm^2 using IWF 250.125.6.9, while the composite beam size is 250 x 400 mm^2 using IWF 250.125.6.9. The yield and ultimate strengths of steel are 240 MPa and 370 MPa, respectively. The floor plan, view, and structural elements detail of the designed building are shown in Fig. 2.

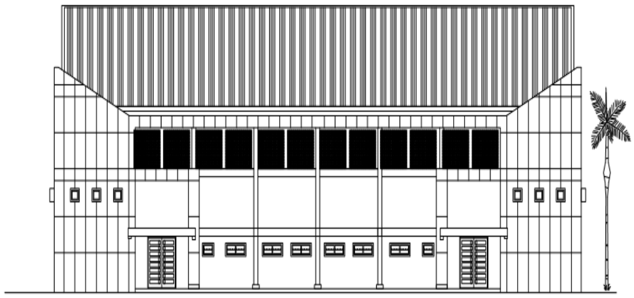
B. Structural Analysis of Existing Structure

The analysis is performed using the structural analysis program's commercial software, ETABS 9.7.1 [6]. The program can present the structural analysis result of an evaluated building structure due to gravity and seismic loads, such as internal forces and displacements. Fig. 3 shows the 3D model of the existing hall building structure.

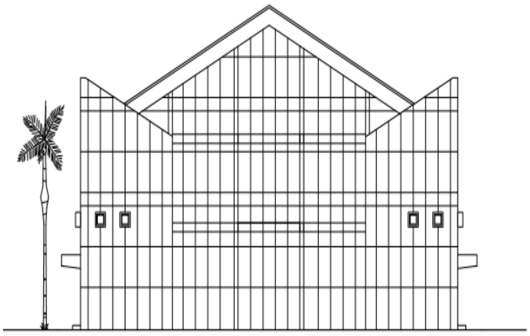
In this analysis, columns and beams have been modeled as frame elements while the slab's in-plane rigidity is simulated by using rigid diaphragm action.



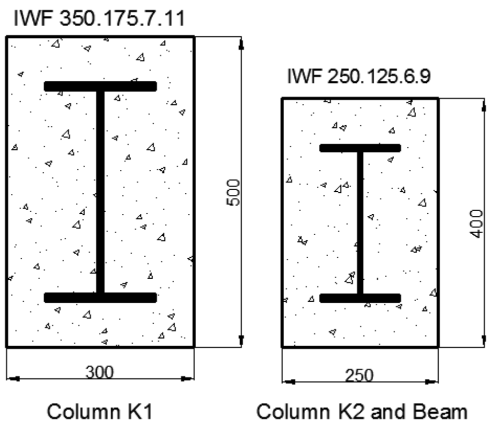
a) The floor plan of the hall building



(b) The front view of the hall building



(c) The side view of the hall building



(d) Detail of structural elements (columns and beam)

Fig. 2 The floor plan, view, and structural elements detail of the designed hall building

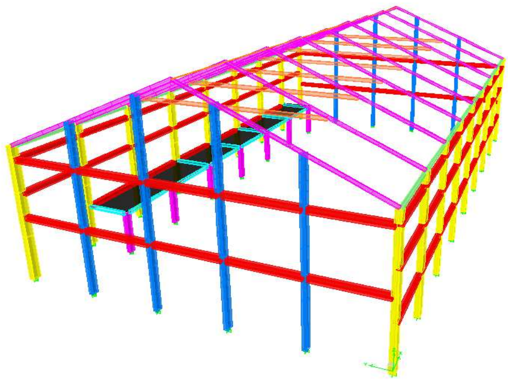


Fig. 3 The 3D modeling of the existing building

In this analysis, the bottom of the columns is assumed to be fixed. To determine the self-weight of the structure, an analysis is conducted based on the concept of equilibrium forces. The building structure is analyzed for the service loads, including the seismic loads calculated using the new Indonesian seismic standard code [7].

In this analysis, the loads applied in the existing building are as follows:

- The dead load consists of a self-weight of columns, beams, flooring for a typical frame, and internal partitions. The analysis software automatically calculated the self-weight of the structural elements.
- The live load was taken to be 500 kg/m^2 for the tribune area [8].
- The wind load was calculated based on SNI 1727:2013, to determine the gust peak wind loads on buildings (roof) and its components. In this analysis, the wind load was calculated by using equivalent static procedures. The calculation results of wind load for the building are 27.121 kg (x-direction) and 12.632 kg (y-direction) for compression; and 13.56 kg (x-direction) and 6.316 kg (y-direction) for tension.
- The seismic loads using the response spectrum based on SNI 03-1726-2012 are used in dynamic response analysis. The type of soil in the building area is medium soil. The response spectrum design of Padang for medium soil is shown in Fig. 4 [9].

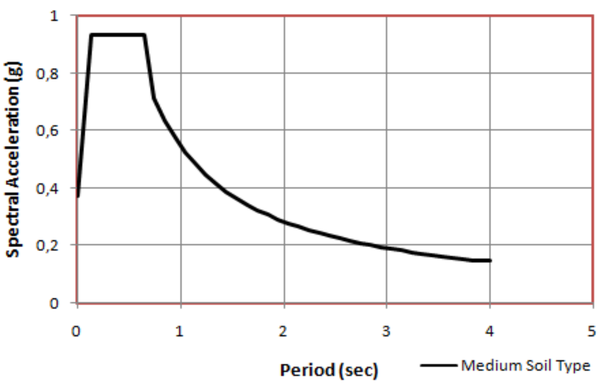


Fig. 4 The response spectrum design of Padang for medium soil [9]

According to SNI 03-1726-2012 about earthquake zoning map, 1 second bedrock acceleration value (S_1) for Padang area was 0.6 g and 0.2 seconds bedrock acceleration value (S_S) for Padang area was 1.398 g. The Seismic Design Categories (SDC) of the research object is the D category with the reliability factor (ρ) of 1.3. The required parameters to determine seismic load are the deflection magnification factor (C_d) of the structural system that is taken as 5.5, and the building importance factor (I_e) of 1.5, which are used as an input to the software in determining the load. The load combinations in this analysis are as follows:

- 1.4DL
- 1.2DL + 1.6LL + 0,5Lr
- 1.2DL + 1.6Lr + 1LL
- 1.2DL + 1WL + 1LL + 0,5Lr
- 0.9DL + 1WL
- 1.2DL + 1.1LL + 0.3(ρQEx + 0.2SDSDL) + 1(ρQEy + 0.2SDSDL)
- 1.2DL + 1.1LL + 1(ρQEx + 0.2SDSDL) + 0.3(ρQEy + 0.2SDSDL)
- 0.9DL + 0.3(ρQEx – 0.2SDSDL) + 1(ρQEy - 0.2SDS DL)
- 0.9DL + 1(ρQEx – 0.2SDSDL) + 0.3(ρQEy- 0.2SDS DL)

Where: DL = dead load, LL = live load, Lr = live load in the roof, WL = wind load, and QE = effect of horizontal seismic forces (x and y directions).

In this analysis, the damping of dynamic response analysis is 0.05. To simulate the planned earthquake arbitrary load toward the building structure model, the effect of the seismic load on the primary directions is considered to be 100% effective at the same time as the effect of the seismic load in the perpendicular direction to the main direction is only 30% effective.

III. Results and Discussion

A. The Capacity of Existing Building Structure

The existing building structure's capacity was evaluated in terms of the load-bearing capacity of the structural elements, displacement, inter-story drift, and bearing capacity of the foundations. The column strength is examined by calculating the columns' internal forces by the combination of service loads and column capacity (in terms of bending moment and axial). These values were compared. All column structures are stated as being quite strong because the internal force's value is less than or equal to the capacity, as shown in Table 1.

TABLE I
THE LOAD BEARING CAPACITY OF EXISTING COLUMNS

Elv. (m)	Portal	Bending Moment Capacity			Axial Capacity		
		M_u (kNm)	φM_n (kNm)	$\varphi M_n \geq M_u$	N_u (kN)	φN_n (kN)	$\varphi N_n \geq N_u$
0.0-4.5	1, 9	115	131	OK	217.8	3051	OK
4.5-8.3	1, 9	135	139	OK	126.8	1721	OK
0.0-3.0	A	85.4	208	OK	237.3	2668	OK
3.0-6.0	A	133	208	OK	153.7	3052	OK
6.0-8.3	A	99.8	208	OK	81.9	3052	OK
0.0-6.0	G	72.8	208	OK	149.1	2038	OK
0.0-3.0	G	131	208	OK	312.2	2668	OK
3.0-6.0	G	103	208	OK	154.0	3052	OK
6.0-8.3	G	135	208	OK	81.9	3052	OK

Table 2 shows the load-bearing capacity of the beams. From the table, it can be seen that the overall bending performance of the structural beam is reliable to support the building loads, but the beams need to be strengthened from shear.

TABLE II
THE LOAD BEARING CAPACITY OF EXISTING BEAMS

Elv. (m)	Span (m)	Bending Moment Capacity			Shear Capacity		
		M_u (kgm)	φM_n (kgm)	$\varphi M_n \geq M_u$	V_u (kg)	φV_n (kg)	$\varphi V_n \geq V_u$
3.0	4.6	1971.6	5398	OK	3121	1322	NOT
4.5	4.25	3115.8	5793	OK	4303	1721	NOT
6.0	4.6	1654.2	5398	OK	2591	1322	NOT
8.3	4.25	3393.0	5793	OK	4630	1721	NOT
	4.6	904.9	5398	OK	1381	1322	NOT

In addition, the inter-story drift (Δs) meets the required permit limits (Δa), as seen in Table 3. The maximum story drift for x and y-direction is 1.16 mm and 1.66 mm, respectively. These values are less than the allowable inter-story drift of 44.2 mm; that indicates that the building structure can carry the applied loads. The pile foundation with 2.6 m depth and 1 m diameter was used in the Law Faculty hall building. The type of soil in the building area was obtained based on the soil test approach.

TABLE III
THE INTER-STORY DRIFT OF EXISTING STRUCTURE

Story	H (m)	Δa (mm)	X-Direction			
			δ (mm)	Drift (mm)	Δs (mm)	Note Δa ≥ Δs
Base	0	0	0	0	0	OK
1	3.0	57.7	0.14	0.14	0.77	OK
2	1.5	28.8	0.24	0.1	0.55	OK
3	1.5	28.8	0.39	0.15	0.83	OK
4	2.3	44.2	0.6	0.21	1.16	OK

Story	H (m)	Δa (mm)	Y-Direction			
			δ (mm)	Drift (mm)	Δs (mm)	Note Δa ≥ Δs
Base	0	0	0	0	0	OK
1	3.0	57.7	0.1	0.1	0.55	OK
2	1.5	28.8	0.16	0.06	0.33	OK
3	1.5	28.8	0.26	0.1	0.55	OK
4	2.3	44.2	0.38	0.12	1.66	OK

$\Delta s = \text{Drift} * C_d / I_e$
$\Delta a = 0.015 * H / \rho$

TABLE IV
THE CHECKING OF FOUNDATION CAPACITIES

Data	Formula	Results	Note
Soil test data (0,5D and 1,1D)	$q_{c\ average}$	4333 kN/m^3	
$A_s = (¼*\pi*D^2)$ $q_{c\ average}$	$Q_p = A_s * q_{caverage}$	3401.4 kN	
Q_p SF = 3	$Q_{ult} = Q_p$ / SF	1134 kN	
Q_{ult} Q_m = 212,64 kN (From ETABS)	$Q_{ult} \geq Q_m$	1134 kN ≥ 212,64 kN	OK

Table 4 shows the calculation results of the bearing capacity for the existing foundations. The table shows that the foundations have a strong enough capacity to resist all applied loads. From the results of performance evaluation by using the SNI 03-1726-2012, it was found that the building structure is not able to withstand the applied loads, especially the shear force in the several beams, so the existing building should be strengthened.

B. Strengthening Recommendations

Strengthening a building structure should be considered a good alternative solution when the existing structure deteriorates or does not have sufficient capacity to resist the forces. The strengthening of the structure, especially in resisting the seismic load, can be designed by determining the weak links in the structure. The strengthening strategy was usually carried out by reducing the overall dead load and then providing the lateral load resisting system in the structure [10].

The weak building structures must be strengthened to improve their capacity to meet the structure's same requirements based on the current building code. Strengthening buildings is effective and efficient rather than reconstructing a new building [11]. A decision to strengthening a building generally was taken by considering some aspects, not only the strengthening cost but also the method and material used, environmental, aesthetic, and to minimize the maintenance and repair needs. The term "strengthening strategy" is defined as an option to the enhancement of one or more *seismic* response parameters (stiffness, strength, and ductility) of the structural elements or the whole building [12].

Several methods and materials had been reported to be viable for strengthening the existing concrete-encased steel structures. In this study, three strengthening methods were proposed: adding steel bracing, increasing the web thickness of IWF beams, and adding the reinforcement bar to the beams.

1) Strengthening by Adding Steel Bracing: The addition of steel bracing is a strengthening method by adding a diagonal stiffener to the structural elements. Based on the previous research, retrofitting using steel bracing reduces the internal force acting on the beam to reach ± 70% [13]. The steel bracing dimension used for the strengthening of this building is IWF 200.100.5.5.8 with f_y = 240 MPa. The type of steel bracing used is the inverted-V type, which can be applied to the building structure without reducing the building's door and opening positions. Three models of the strengthened building structure using the bracing were analyzed. Models 1 and 2 are the building with steel bracing on the x and y-directions, respectively (Figs. 5 and 6), while on Model 3, the steel bracings were installed on both x and y-directions of the building (Fig. 7).

Tables 5, 6, and 7 show the beams' load bearing capacity for strengthening the building with steel bracing. The presence of steel bracing increases the bending moment and shear force capacities of the beams.

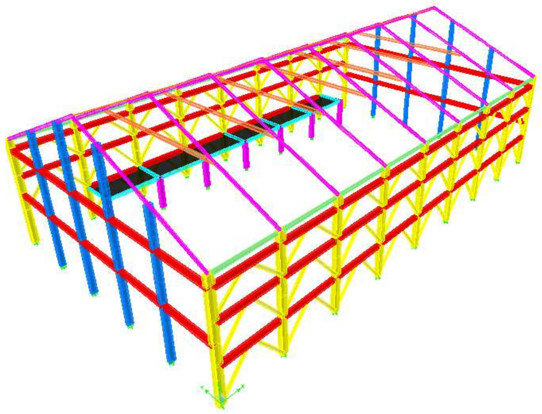


Fig. 5 The 3D model of the structure with steel bracing on X-direction

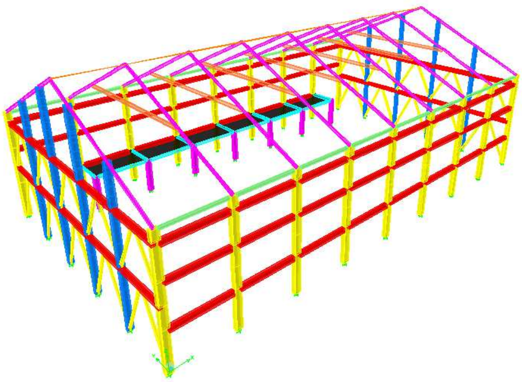


Fig. 6 The 3D model of the structure with steel bracing on Y-direction

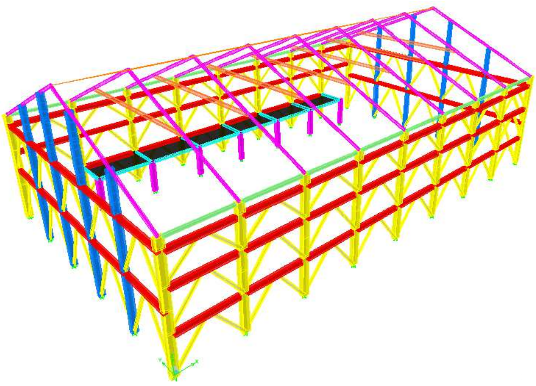


Fig. 7 The 3D model of the structure with steel bracing on X and Y-directions

TABLE V
THE LOAD BEARING CAPACITY OF BEAMS AFTER ADDING STEEL BRACING ON X-DIRECTION

Elv. (m)	Span (m)	Bending Moment Capacity			Shear Capacity		
		M_u (kgm)	φM_n (kgm)	$\varphi M_n \geq M_u$	V_u (kg)	φV_n (kg)	$\varphi V_n \geq V_u$
3.0	4.6	584.8	6584	OK	1685	3486	OK
4.5	4.25	3109.6	5793	OK	4299	1721	NOT
6.0	4.6	529.6	6584	OK	1428	3486	OK
8.3	4.25	3395.6	5793	OK	4630	1721	NOT
	4.6	326.4	6584	OK	770	3486	OK

TABLE VI
THE LOAD BEARING CAPACITY OF BEAMS AFTER ADDING STEEL BRACING ON Y-DIRECTION

Elv. (m)	Span (m)	Bending Moment Capacity			Shear Capacity		
		M_u (kgm)	φM_n (kgm)	$\varphi M_n \geq M_u$	V_u (kg)	φV_n (kg)	$\varphi V_n \geq V_u$
3.0	4.6	1970	5398	OK	3120	1322	NOT
4.5	4.25	722	7044	OK	2009	3914	OK
6.0	4.6	1651	5398	OK	2588	1322	NOT
8.3	4.25	2384	7044	OK	2526	3914	OK
	4.6	899	5398	OK	1378	1322	NOT

TABLE VII
THE LOAD BEARING CAPACITY OF BEAMS AFTER ADDING STEEL BRACING ON BOTH X AND Y-DIRECTIONS

Elv. (m)	Span (m)	Bending Moment Capacity			Shear Capacity		
		M_u (kgm)	φM_n (kgm)	$\varphi M_n \geq M_u$	V_u (kg)	φV_n (kg)	$\varphi V_n \geq V_u$
3.0	4.6	585	6584	OK	1685	3486	OK
4.5	4.25	722	7044	OK	2001	3914	OK
6.0	4.6	527	6584	OK	1431	3486	OK
8.3	4.25	2389	7044	OK	2525	3914	OK
	4.6	322	6584	OK	768	3486	OK

From the analysis results of the strengthened building models, it is found that Model 3 has better performance than the other two models. The strengthening by adding the bracing effectively reduced the bending moment and sheer force of the beams around 63.91% and 38.79%, respectively, and increases the capacity of the beams up to 100% of the initial capacity.

2) Strengthening by Increasing the Web Thickness of IWF Beams: Beam is a structural member, which has the lowest level in strength requirement for the earthquake load. The beam can be designed and detailed more ductile than columns because the beam does not carry the compression load [14]. The second strengthening alternative was conducted by increasing the thickness of IWF steel web with a thickness 4 mm for the 4.6 m length beam and a thickness 8 mm for the 4.25 m length beam, by assuming it will increase the shear capacity of weak beams. The detail and dimensions of web thickness are shown in Figs. 8 and 9.

The analysis results of strengthening using this method can be seen in Table 8. As seen in the table, the maximum shear force is less than the nominal shear strength value. In elevation 3.0, the highest shear force is 3121 kg, while the nominal shear strength value is 3709 kg. A similar trend was also observed in upper elevation, in which the maximum shear force is 4631 kg, while the nominal shear strength is 7434 kg. The results of the evaluation stated that the beams using this strengthening method in all of the span are meet the requirement, which is $\phi V_n \geq V_u$. In addition, the increase of the beam capacity to resist shear force is more than 100% of the initial capacity.

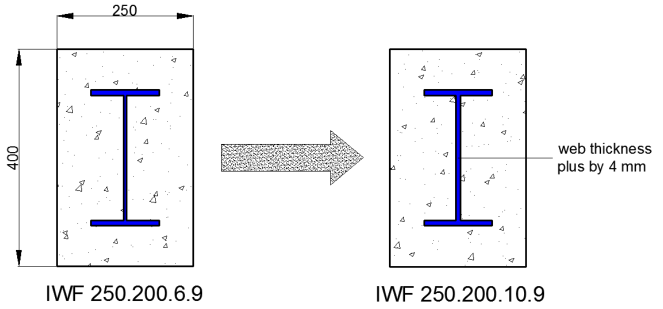


Fig. 8 The detail of adding the 4 mm of IWF web thickness (beam L=4.6 m)

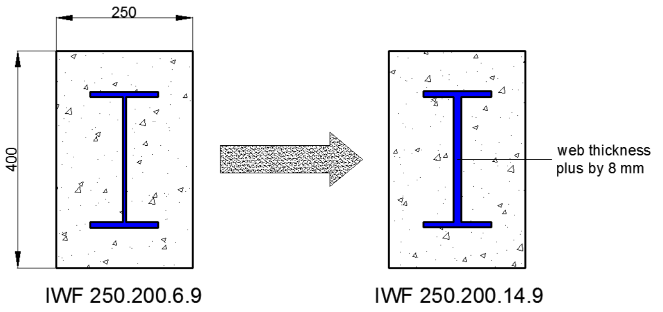


Fig. 9 The detail of adding the 8 mm of IWF web thickness (beam 4.25 m)

TABLE VIII
THE LOAD BEARING CAPACITY OF BEAMS AFTER INCREASING THE WEB THICKNESS OF IWF BEAM

Elv. (m)	Span (m)	Checking of Bending Moment			Checking of Shear		
		M_u (kgm)	φM_n (kgm)	$\varphi M_n \geq M_u$	V_u (kg)	φV_n (kg)	$\varphi V_n \geq V_u$
3.0	4.6	1987	5398	OK	3121	3709	OK
4.5	4.25	3133	5793	OK	4303	7434	OK
6.0	4.6	1668	5398	OK	2592	3709	OK
8.3	4.25	916	5793	OK	4631	7434	OK
	4.6	3443	5398	OK	1381	3709	OK

3) Strengthening by Adding Reinforcement Bars to The Beams: The third strengthening alternative applied to the existing building structure is by adding 4D10 bending reinforcement and Ø8-150 shear reinforcement to the composite beam element, as shown in Fig. 10.

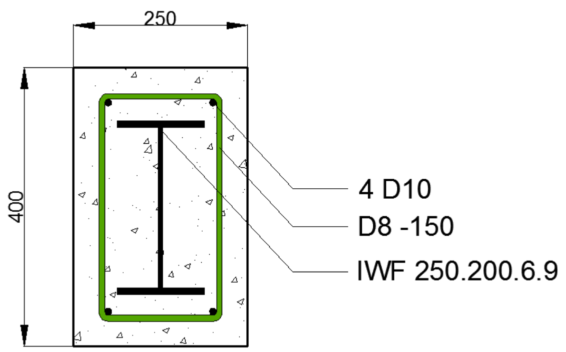


Fig. 10 The detail of strengthening by adding the reinforcement bars.

In this case, the concrete function in the beam was calculated as reinforced concrete, and it will contribute to carrying the working loads. The results of this method are viewed in Table 9.

TABLE IX
THE LOAD BEARING CAPACITY OF BEAMS AFTER ADDING THE REINFORCEMENT BAR TO THE BEAM

Elv. (m)	Span (m)	Bending Moment Capacity			Shear Capacity		
		M_u (kgm)	φM_n (kgm)	$\varphi M_n \geq M_u$	V_u (kg)	φV_n (kg)	$\varphi V_n \geq V_u$
3.0	4.6	1972	7253	OK	3121	9730	OK
4.5	4.25	3116	7648	OK	4304	10129	OK
6.0	4.6	1654	7253	OK	2592	9730	OK
8.3	4.25	3024	7648	OK	4631	10129	OK
	4.6	905	7253	OK	1381	9730	OK

Table 9 shows that the strengthened beam's capacity increases twice the existing beam so that all of the beams can reduce the seismic risks and lead to a more resistant structure. Reviewing the analysis of the multipurpose building leads to strengthening actions that have cost implications. Table 10 shows the total volume, unit price, and bill of quantity (BOQ) of the three strengthening methods [15]. It can be seen from the table, the addition of bending and shear reinforcement on the composite beams has the cheapest cost among the other two methods. Also, this method is easy to be constructed in the building.

Strengthening by adding the bracing requires more expensive cost and fieldwork because the steel bracing should be installed throughout the building. This might disrupt the accessibility of the building. For the strengthening method by increasing the web thickness of IWF beams, although the cost is cheaper than adding the bracing, work on the field was quite complicated.

TABLE X
THE COMPARISON OF BOQ FOR THE THREE STRENGTHENING METHODS

Method	Work Item	Volume	Unit Price of Work (IDR)	BOQ + TAX 10% (IDR)
Steel Bracing (III)	Steel Working	11,323 kg	19,833	224,567,248
Adding Web Thickness of IWF	Adding web thickness	25 sheet and 1,178 kg	3,913,950 and 11,208	111,243,100
Adding Reinforce-ment Bar	Reinfor-cement bar	26.75 kg	1,446,000	44,594,200

IDR: Indonesian Rupiah

IV. CONCLUSION

The existing Law Faculty hall building of Andalas University is not able to resist the working loads. The building structure should be strengthened before continuing the construction. The strengthening of the existing hall building structure using steel bracing reduces the building's internal forces significantly. The reductions of bending moment and sheer force of the beams are 63.91% and 38.79%, respectively. Besides, the steel bracing increases the beam capacity up to 100% of the initial capacity, with estimated work cost IDR 247,024,000.

Strengthening method by increasing the web thickness of IWF steel beams improves these beams' capacity to resist shear force more than 100% of the initial capacity, having estimated work cost IDR 111,243,100. Strengthening the building by adding 4D10 bending and Ø8-150 shear reinforcement bars increases the beam capacity twice of the existing beam capacity, with an estimated work cost IDR 44,594,200. Comparing the three alternative strengthening methods, the addition of the reinforcement bars on composite steel beams is the most effective to be done because it is more economical and more accessible in the construction.

Nomenclature

M_u	ultimate moment	kNm
M_n	nominal moment (capacity)	kNm
V_u	ultimate shear	kN
V_n	nominal shear (capacity)	kN
H	floor height	m
φ	reduction factor for capacity	
δ	displacement	mm
$q_{c\ av.}$	penetration of conus (average)	kN/m^3
Q_p	tip resistance value	kN
A_s	area of reinforcement bar cross-section	mm^2
SF	safety factor	
Q_{ult}	supporting capacity of foundation	kN
Q_m	force from the building loads	kN

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