4th International Conference on Rehabilitation and Maintenance in Civil Engineering
Best Western Premier Hotel, Solo Baru, July 11-12 2018

A Comparison of Retrofitting Methods on Nursing Faculty Building of Andalas University with Concrete Jacketing and Shear Wall Systems

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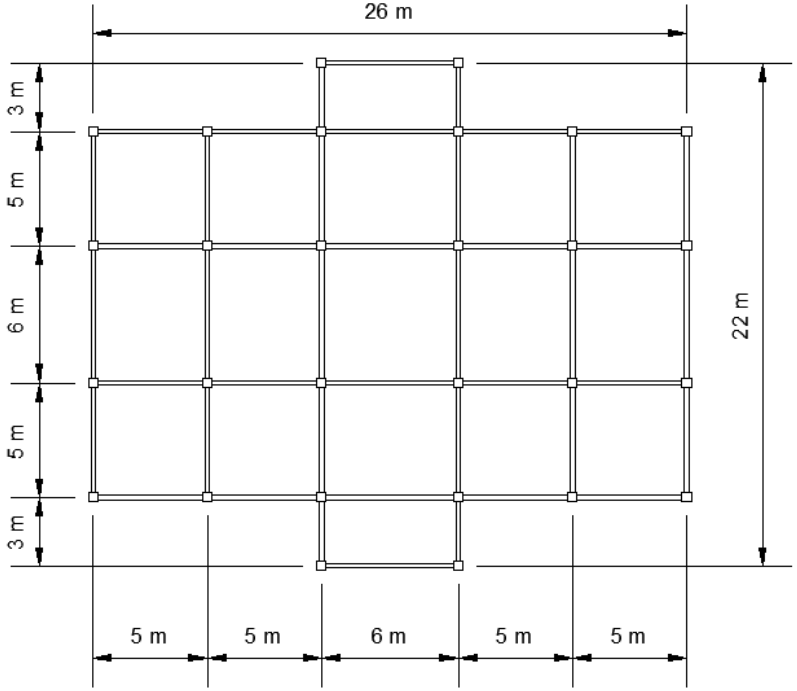
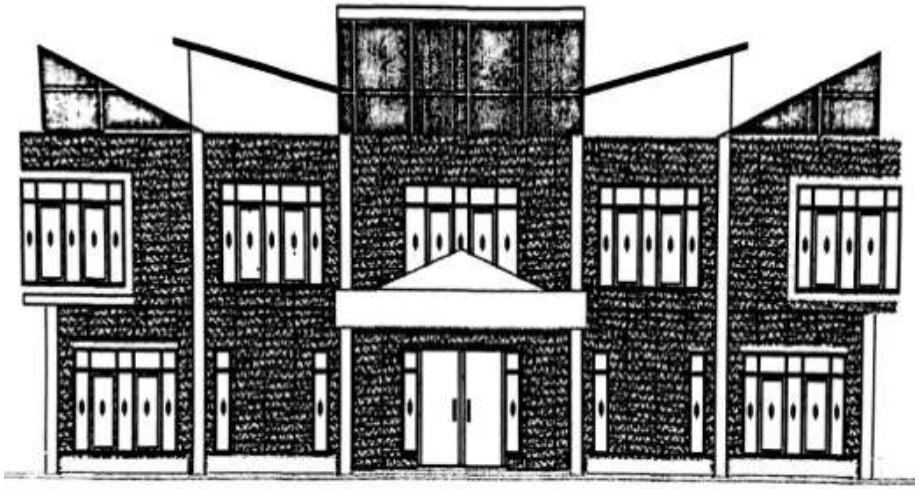
INTRODUCTION

- Andalas University is a great university located in Padang City, which is in the **high seismic region**.
- The Nursing Faculty was established on the 3rd of August 2012. To fulfill the administrative eligibility, **a new Nursing Faculty building was built**.
- The building was planned as **a two-story reinforced concrete frame structure**.





The plan and front view of the building

INTRODUCTION…

- During the construction, the concrete compressive strength is low (**fc'=15 MPa**), which does not meet the strength requirement (fc'=20 MPa).
- So that the construction was **stopped** and it **cannot be continued**.

Photo of the existing building (July 2017)

INTRODUCTION…

- The performance of the structures **must be improved** by applying seismic retrofitting methods. .
- **Retrofitting** are more cost-effective and time-efficient solution rather than replacement of seismic deficient buildings.
- This study focuses on the seismic evaluation of the existing building structure and retrofitting the building using two alternatives: **concrete jacketing** and **adding a shear wall**.

BUILDING DATA

- Data were obtained from the **design consultants**.
- F_c'= **15 MPa** (performed by the hammer test).
- F_y = **400 Mpa (**Longitudinal reinforcement) and **240 Mpa** (shear reinforcement).
- As-built drawing Data:

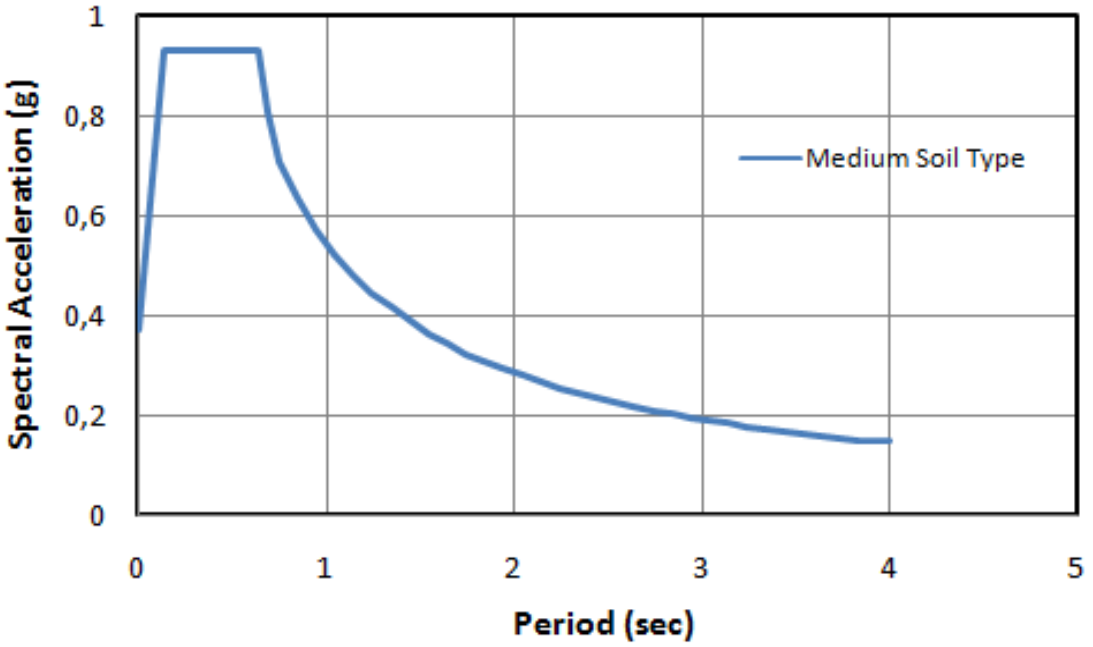
  - Number of the storeys: **2**
  - Height of the building: **8 m**
  - Column: K1 (40 x 40) and K2 (25 x 25) cm^2
  - Beam: B1 (30 x 50); B2 (20 x 30); and B3 (20 x 25) cm^2
  - Length x width of the building: 26 m x 22 m
  - The thickness of slab: **12 cm**

LOADS

Load	Component	Value	Load	Component	Value
Dead	Reinforced Concrete	2400 kg/m^3	**Live**	Office	250 kg/m^2
	Masonry wall (1/2 brick)	250 kg/m^2		Toilet	250 kg/m^2
	Plafond	20 kg/m^2		Roof (concrete)	300 kg/m^2
	Space (1cm thickness)	21 kg/m^2		Stair	300 kg/m^2
	Floor cover (1cm thickness)	24 kg/m^2	SNI 1727:2013		
	MEP Installation	25 kg/m^2			

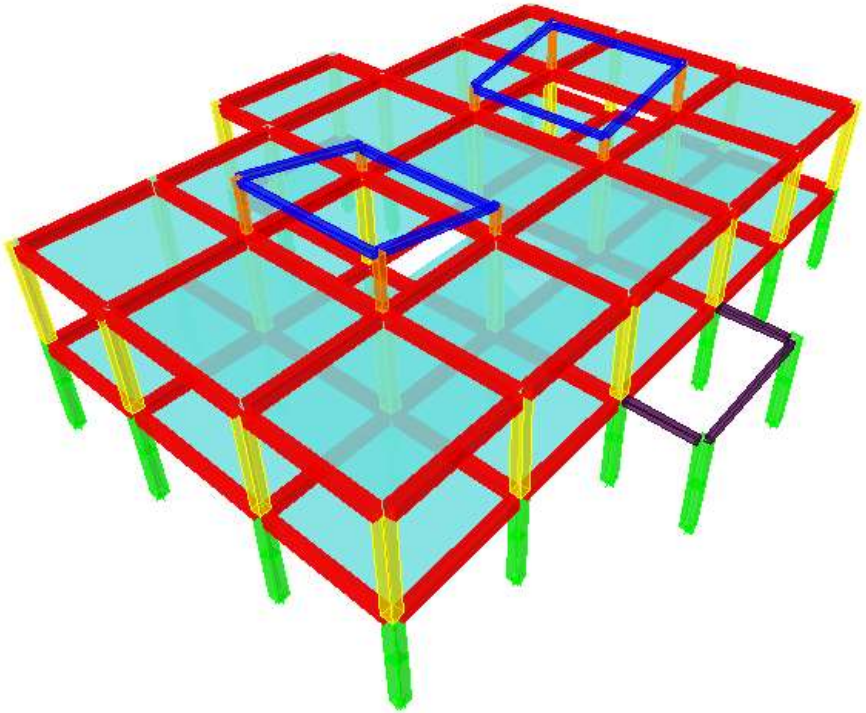
LOADS ...

- The earthquake load uses the response spectra analysis (dynamic analysis) referring to Indonesian Public Work Department (Puskim PU) data, which has been adapted in **SNI 1726:2012**.
- The building is located in the area of Limau Manis with **medium soil condition**. The earthquake reduction factor (R) is **8**, and the seismic importance factor (I_e) is **1.5**.



EVALUATION OF EXISTING BUILDING STRUCTURE

- The structure is modeled and analyzed by using ETABS v9.7.1 software.



LOAD-BEARING CAPACITY OF THE EXISTING STRUCTURE

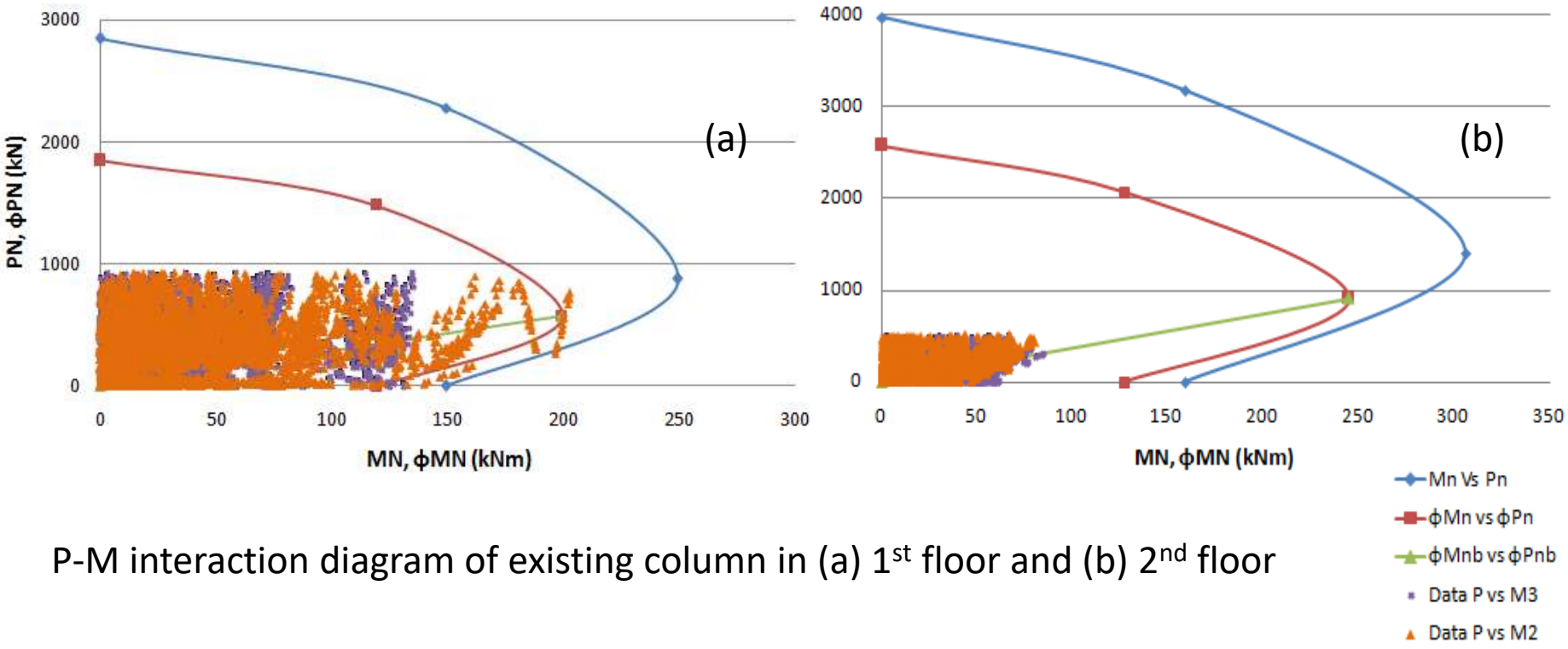
Flexural and shear capacities on the existing beam

Story	Cross Section b x h (mm^2)	Reinforcement Installed		Mu (kNm)	Mn (kNm)	Mu ≤ Mn	Vu (kN)	Vn (kN)	Vu ≤ Vn
		Tens.	Comp.						
1st	300 x 500	5 D 16	3 D 16	62,70	138,45	**OK**	89,22	298,39	**OK**
2nd	300 x 500	5 D 16	3 D 16	61,83	138,45	**OK**	23,45	298,39	**OK**

- The analysis of the capacity of the beam uses the largest cross-section and the longest span one, and then the capacity is compared to the internal force that occurred due to the working loads.
- The beam can resist the working loads.

LOAD-BEARING CAPACITY OF THE EXISTING STRUCTURE ...

- Based on P-M interaction diagram, the bending capacity of the columns on the 1st floor is not capable of carrying the working loads.



P-M interaction diagram of existing column in (a) 1st floor and (b) 2nd floor

LOAD-BEARING CAPACITY OF THE EXISTING STRUCTURE ...

- The column shear capacity is capable of carrying the shear force.

Story	Cross Section (mm^2)	Reinforcement Installed		Mu (kNm)	Mn (kNm)	Mu ≤ Mn	Vu (kN)	Vn (kN)	Vu ≤ Vn
		Flex.	Shear						
1st	400 x 400	12 D 16	10 - 100	202,56	119,42	NOT	74,80	1993	OK
2nd	400 x 400	12 D 16	10 - 100	83,08	126,70	OK	45,31	2193	OK

INTER-STORY DRIFT OF THE EXISTING STRUCTURE

- The amount of inter-story drift in the X and Y directions meets the required allowable drift.

Story	Δa (mm)	Disp. X (mm)	Drift X (mm)	Δs Y (mm)	Δs ≤ Δa	Disp. Y (mm)	Drift Y (mm)	Δs Y (mm)	Δs ≤ Δa
1st	46,15	5,20	5,20	19,06	**OK**	5,64	5,64	20,68	**OK**
2nd	46,15	11,27	6,07	22,26	**OK**	11,97	6,33	23,21	**OK**

FOUNDATION OF THE EXISTING STRUCTURE

- The foundation has enough capacity to resist all loads applied in the building structure.

	Formula	Value
q_c	data of sondir	0.8B and 0.7B
$q_{c\ average}$	$(\Sigma\ q_c) / n$	2950 kN/m^2
Q_{full}	$q_{c\ average}$ / SF	983.33 kN
Q_{ult}	ETABS	674.47 kN
Check : $Q_{full} \geq Q_{ult}$ ... (OK)		

EVALUATION RESULTS OF EXISTING STRUCTURE

- From the result of the performance evaluation and structural strength to SNI 1726:2012, the building structure **was unable to withstand the working load**, so that the building structure should be **retrofitted**, especially for columns on the 1st floor.

RETROFITTING METHODS (TECHNIQUES)

- **Local Retrofit**

  Retrofitting structure with **concrete column jacketing**

- **Global Retrofit**

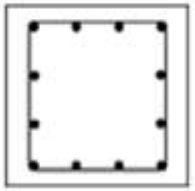
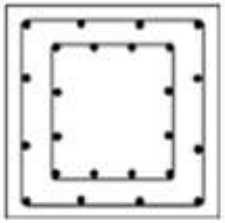
  Retrofitting structure with **shear wall**

RETROFITTING STRUCTURE WITH CONCRETE COLUMN JACKETING

- Add the concrete (dimension) with longitudinal and transverse reinforcement around the existing columns.
- Two main purposes of jacketing of columns:

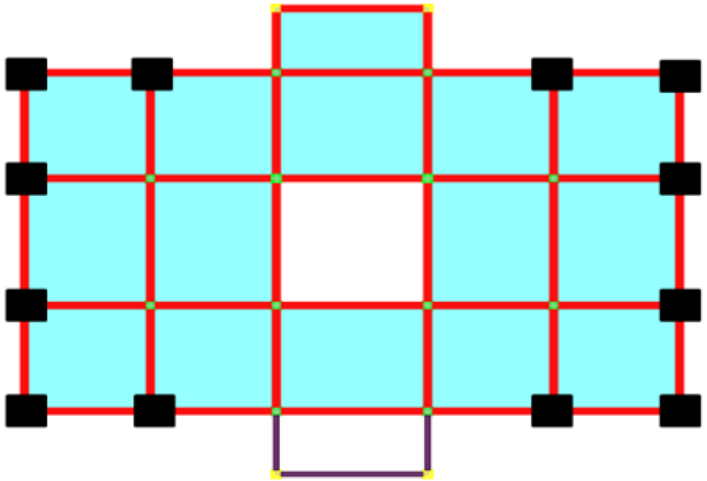
  (a) to **increase the shear capacity of columns**

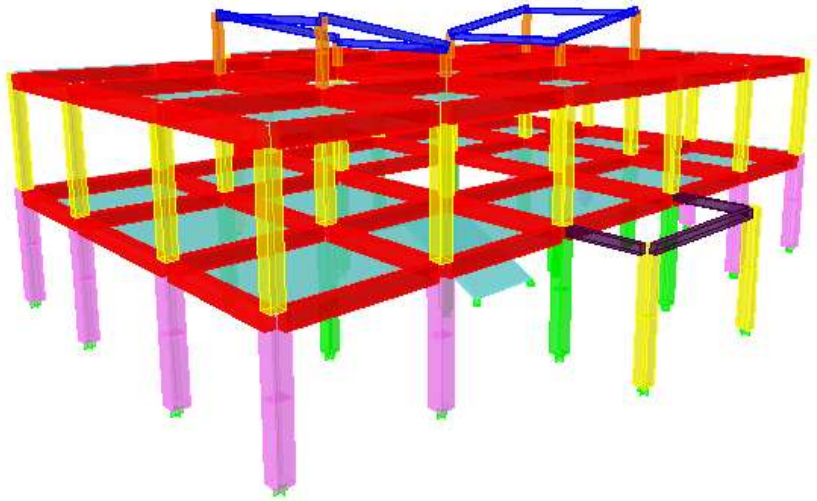
  (b) to **improve the column's flexural strength**

Column		
	Existing	**Retrofitting**
Cross section	400 x 400 mm^2	500 x 500 mm^2
Flexural reinforcement bar	12 D 16	24 D 16
Shear reinforcement bar	Ø 10 – 100 mm	Ø 10 – 100 mm

RETROFITTING STRUCTURE WITH CONCRETE COLUMN JACKETING ...

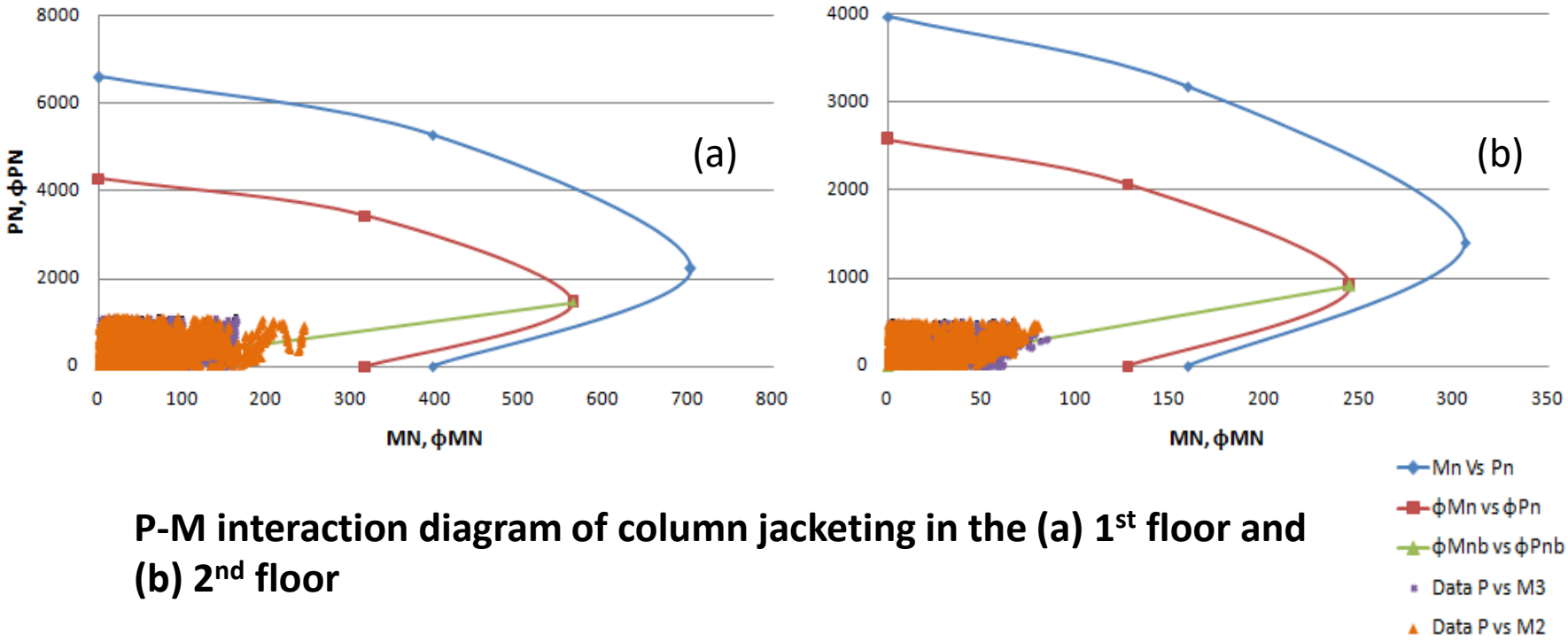
- Modeling the column in concrete jacketing on ETABS is performed by **enlarging the cross-sectional dimension** and **adding the reinforcement** in accordance with the planned amount for the reinforcing column.





LOAD BEARING CAPACITY AFTER JACKETTING OF THE COLUMNS

- The jacketed column leads to the internal force reduction and also make the bending and axial capacities of the 1st floor capable of resisting the working loads.



P-M interaction diagram of column jacketing in the (a) 1st floor and (b) 2nd floor

LOAD BEARING CAPACITY AFTER JACKETTING OF THE COLUMNS…

- The column shear capacity after jacketting is capable of carrying the shear force.

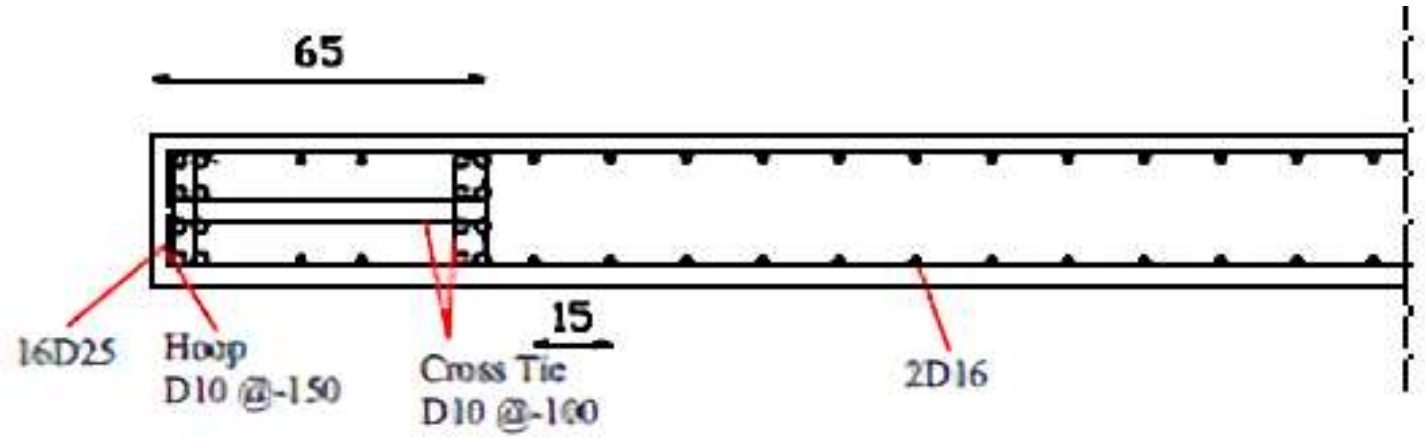
Story	Cross Section (mm^2)	Reinforcement Installed		Mu (kNm)	Mn (kNm)	Mu ≤ Mn	Vu (kN)	Vn (kN)	Vu ≤ Vn
		Flex.	Shear						
1st	500 x 500	24 D 16	10 - 100	243,08	315,88	**OK**	92,10	2443	**OK**
2nd	400 x 400	12 D 16	10 - 100	83,08	126,70	**OK**	45,31	2193	**OK**

INTERNAL FORCES AND DISPLACEMENTS

- The addition of jacketing to the column structure gives an increase in the column capacity. The largest percentage increase in the capacity design was around **165%**, **23**%, and **132**% for bending moment, shear, and axial, respectively.
- The decrease of displacements in the retrofitting structure compared to the existing structure is about 13% both for the X and Y directions.

RETROFITTING STRUCTURE WITH SHEAR WALL

- Adding structural walls is one of the most common structure-level retrofitting methods to strengthen existing structures. This approach is **effective for controlling global lateral drifts** and for **reducing damage** in frame members.
- The shear wall thickness used was calculated based on SNI 2847:2002, where 0.14m < t < h/24 m and found that the optimum thickness of the shear wall is **20 cm**.



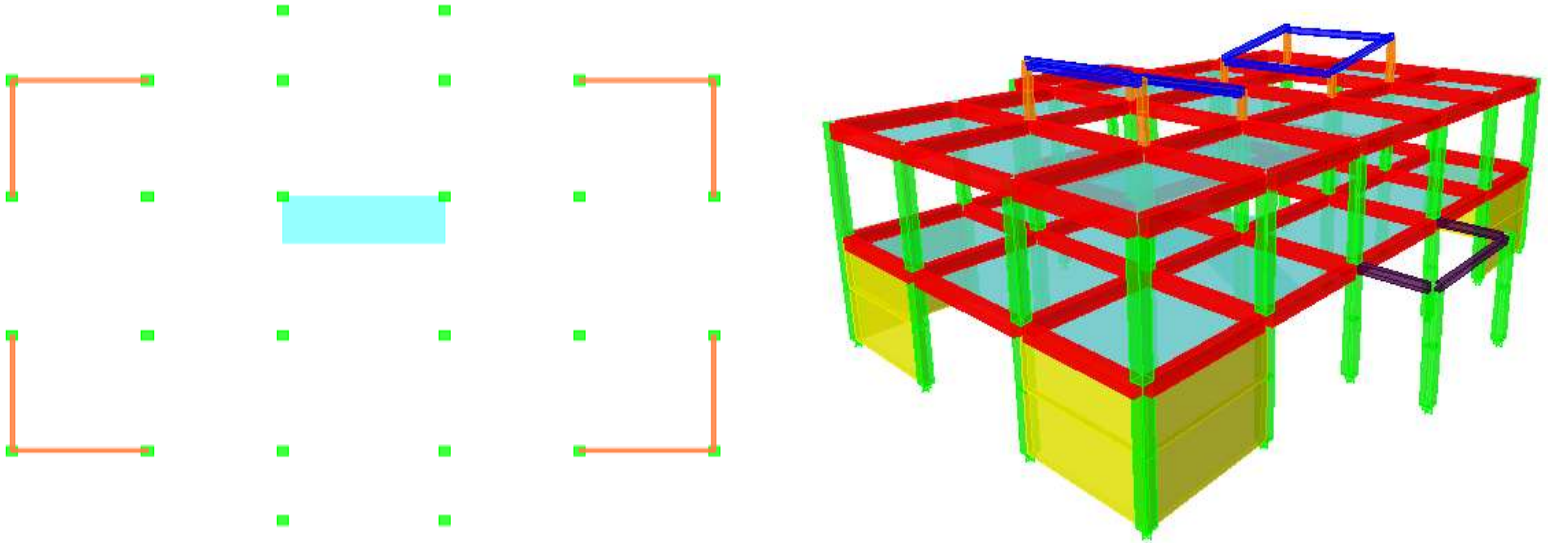
RETROFITTING STRUCTURE WITH SHEAR WALL ...

- The shear wall was placed in the corner of the building on the 1st floor only. The shear wall used had:

  Length x height x thickness: 5 m x 4 m x 20 cm,

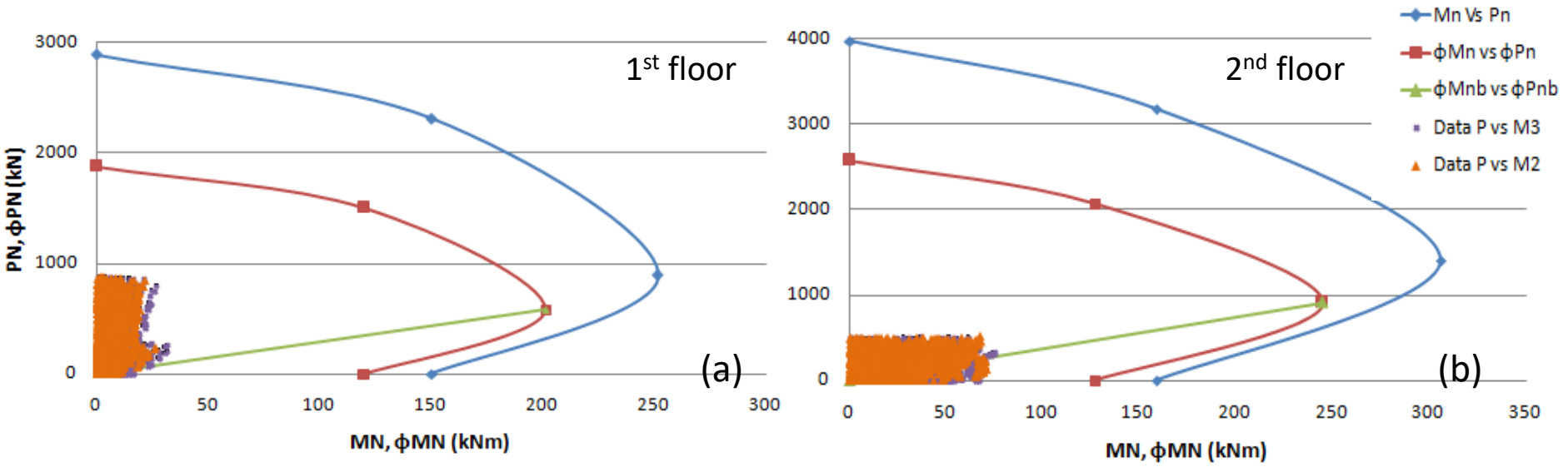
  F‘c = 25 MPa,

  Fy = 400 Mpa (reinforcement bar D-13 mm)



Location of shear wall placement and the 3D modeling of the building

LOAD-BEARING CAPACITY AFTER ADDING SHEAR WALL



P-M interaction diagram of a column after adding the shear wall

The column shear capacity after adding shear wall

Story	Cross Section (mm^2)	Reinforcement Installed		Vu (kN)	Vn (kN)	Vu ≤ Vn
		Diameter (mm)	Space (mm)			
1st	400 x 400	10	100	19,71	1933,66	OK
2nd	400 x 400	10	100	42,07	2193,66	OK

INTERNAL FORCES AND DISPLACEMENTS

- The addition of the shear wall to the structure gives a decrease of internal forces in the columns. The largest percentage of decline was around **83%**, **48%**, and **6%** for bending moment, shear, and axial forces, respectively.
- The decrease of displacements between the existing and retrofitted structure is around **84%** and **90%** for the X and Y directions, respectively.

INTER-STORY DRIFT OF THE RETROFITTING STRUCTURE

- The inter-story drift of the structure by adding shear wall systems are in accordance with the allowable limit required by SNI 1726:2012.

Story	Δa (mm)	Disp. X (mm)	Drift X (mm)	Δs X (mm)	Δs ≤ Δa
1st	46,15	0,83	0,83	3,04	OK
2nd	46,15	4,41	3,58	13,12	OK

Story	Δa (mm)	Disp. Y (mm)	Drift Y (mm)	Δs Y (mm)	Δs ≤ Δa
1st	46,15	0,55	0,55	2,02	OK
2nd	46,15	4,67	4,12	15,11	OK

THE COMPARISON OF BOQ ON THE TWO RETROFITTING METHODS

Method	Item of Work	Unit	Vol.	Unit Price of Work (IDR)	BOQ (IDR)	Total BOQ + 10% Tax (IDR)
Concrete Jacketing	Demolition of Concrete Cover	m^3	2.76	519,621	1,436,649	149,637,400
	Giving the Concrete Glue	m^2	61.44	42,571	2,615,563	
	Work on Reinforced Concrete Column 50 x 50	m^3	7.09	18,628,854	131,981,699	
Shear Wall	Work on Reinforced Concrete Shear Wall	m^3	24.00	11,122,699	266,944,776	294,650,800
	Giving the Concrete Glue	m^2	21.60	42,571	919,543	

Note: 1 US $ = 14,000 Indonesian Rupiah (IDR.)

CONCLUSIONS

- The bending capacity of the columns on the 1st floor is not capable of carrying the working loads, while the beam capacity and the inter-story drift are safe from the limit standard. **The building structure should be retrofitted**.
- There are **two types of retrofitting** presented in the paper that were conducted in the existing building, **concrete jacketing** to the columns (local retrofit) and adding a **shear wall** (global retrofit).
- All the retrofitting methods lead to a more resistant structure, reducing the seismic risks: lateral displacements decreased, while bending moment and shear force capacities significantly increased.

CONCLUSIONS ...

- Retrofitting with concrete column jacketing increased the load-bearing capacity of the column, by around **165%**, **23%**, and **132%** for bending moment, shear, and axial forces, respectively. Furthermore, it reduced the building displacement by around **13%** in both the X and Y directions.
- Retrofitting with the shear wall reduces the internal force in the building by around **83%**, **48%**, and **6%** for bending moment, shear, and axial forces, respectively. Positively, the decrease of displacement was about **84%** and **90%** in both the X and Y directions, respectively.
- Based on the cost and the ease of the construction, the retrofitting with **column jacketing is recommended** to be applied in the Nursing Faculty - Andalas University building.

Thank you for your attention