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Analysis of Strengthening Beam Structure Case Study on Food Court Building of *Ruang Terbuka Hijau* (RTH) Project at Alun-Alun Kota Kediri

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Beam Loading; Beam Cracking; Repair Method

ABSTRACT
The Green Open Space (RTH) construction in Kediri City includes a food court building utilizing reinforced concrete structures. During construction, cracking issues occurred in several beam structures due to the inability to bear the design loads effectively, necessitating a strengthening approach. This study aims to develop and evaluate a strengthening method for cracked beam structures by employing concrete jacketing. The specific objective is to improve the structural integrity and load-bearing capacity of these beams to ensure the durability and safety of the building. A concrete jacketing technique was used to reinforce the cracked beams, utilizing K-300 ready-mix concrete and additional reinforcing steel. The study involved structural analysis to assess the load-bearing capacity before and after jacketing, and on-site evaluation was conducted to monitor the method's effectiveness. The findings indicate that the jacketing method significantly increased the beams' bending moment capacity and overall structural strength, successfully addressing the cracks and enhancing the beams' ability to bear the intended loads. The reinforced beams showed improved load distribution and structural resilience performance. Concrete jacketing proved to be an effective method for strengthening the cracked beam structures in the Green Open Space project. The study provides valuable insights for similar future construction projects, suggesting that concrete jacketing can be a reliable reinforcement technique to enhance the durability and safety of building structures.

Introduction

Green Open Space (RTH) is part of the open space in an urban area in the form of an area within a certain unit area containing plants, plants, and green spaces both naturally growing and deliberately planted to support ecological, socio-cultural, architectural, comfort, beauty benefits and is basically part of an undeveloped city that functions to improve environmental quality, nature conservation and recreational facilities (Ring et al., 2021; Wang et al., 2021). According to the Minister of Home Affairs Regulation No. 1 Year 2007 on Green Open Space Arrangement in Urban Areas. Many urban areas are revitalizing their green open spaces with concepts that are in accordance with the art in each region so as to form comfort for the community and create beauty for the urban area, such as the example of Kediri City. Kediri City revitalizes its green open space in which there is work on the food court building to support its activities. In the construction of the food court building, there are 2 aspects of work, namely structure and architecture. The construction of the food court building uses a reinforced concrete structure with K-250 concrete specifications and has 2 floors, while the front side of the 2nd floor forms a sloping side above which the landscape area is used as a playground for the people of Kediri city residents.

The construction of the food court building has aspects of reinforced concrete structure work, in which there are several problems. The problem that occurs is that there are cracks in a reinforced concrete structure, namely the beam structure. In a building structure, the main thing that must be planned as carefully as possible is to avoid unwanted things. The structure is a frame or interconnected rods to channel the load into the ground; if the structure has a problem, then the loads that occur cannot be channeled into the ground; therefore, in planning, the structure must be as careful as possible.

Cracks that occur in the main structure, namely the beam. A beam is a structural element that receives forces acting in the transverse direction against its axis, resulting in bending and shear forces along its span (Dipohusodo, 1994; Roy et al., 2021). Cracks occur due to the beam's inability to withstand the loads that work. Cracks arising in the medium category are about 1 mm - 2 mm wide. The cracks are circular, with an average length of about 60 cm, and are found in several areas that amount to about 10 points. The cracking problem will become serious if not handled properly. The problem that occurs is the collapse of a building, which causes many losses to occur. In this case, various studies are needed to handle it so that it becomes a sturdy and safe building (ACI Committe 224, 2007).

Various structural reinforcement methods can overcome the cracks that occur. The method of repairing cracks can be done by means of the concept of jacketing, which is useful for preventing cracks from arising again by enlarging the dimensions of beams and columns. The main advantage of this system is that it increases the strength and ductility limit of concrete, and the second advantage is that jacketing protects against fragment damage. The repaired structure can accept loads because jacketing can reduce shear force failure and bending moment failure, but it can also provide an increase in the capacity of the structure itself so that this jacketing method can solve the existing problems.

Some previous research on the analysis of beam structure reinforcement shows various methods used to improve the performance of reinforced concrete beams. Luastika et al. (2019) examined the flexural reinforcement of reinforced concrete beams using Glass Fiber Reinforced Polymer (GFRP), which increased beam flexural strength up to 1304.99 MPa with a reinforcement percentage of 153%. Furthermore, Puspita et al. (2018) analyzed flexural cracking in high-strength reinforced concrete beams repaired with epoxy injection, focusing on the injection capacity to repair the structure of high-strength concrete beams. Wibisono (2017) added strip steel plates as flexural reinforcement to reinforced concrete beams, which significantly improved the ability of the beams to resist flexure. Kaontole et al. (2015) evaluated the capacity of reinforced concrete columns reinforced with the concrete jacketing method, where this improvement increased the capacity up to 64.25 Kn.

Based on previous studies, there are differences with the current research, which focuses on strengthening beam structures to handle or increase bending moments and shear forces through a concrete jacketing system using concrete reinforcing steel and K-300 ready-mix concrete. The results of this analysis are expected to provide solutions to overcome the problem of cracking in the beam by referring to previous studies as a reference for solving the problem of strengthening the beam structure.

The objective of this research is to identify effective methods for overcoming the repair of cracked beams. In this regard, the research aims to explore repair techniques that can be used to repair cracked beams, including selecting appropriate materials and approaches to improve the structural integrity of the beams. In addition, the research also aims to evaluate the capability of the applied support structure in the context of the beam cracking problem to ensure that the structure remains safe and capable of supporting loads by applicable standards.

Materials and Methods

Framework of Thought

The framework of this research involves several stages in analyzing the problem of cracks in the beams of the Pujasera building. Large loads such as coral, fertile soil, and grass for the playground caused the beam to receive large shear forces and bending moments, eventually triggering cracking. These cracks are about 1-2 mm wide and 60 cm long on average, with 10 crack points in the beam area.

This study aims to design a structural reinforcement using the *concrete jacketing* method, which encloses the old structure with an additional structure. This method was chosen because it is efficient and capable of increasing the load capacity and ductility of the beam. With careful analysis of the working load, *concrete jacketing* is expected to be the right solution for overcoming beam cracks in the Pujasera building.

Project Data Information

The project data includes technical information related to location, number of floors, building dimensions, and materials specifications. Structural materials such as K-250 quality concrete and steel reinforcement BJTP 280 (plain) and BJTS 420 (threaded) are the main references in designing structural reinforcement.

Structural Loads

Structural load analysis involves the identification of gravity loads, earthquake loads, and other load combinations. The dead load is derived from construction materials, while the live load is from human activities and goods on top of the structure. These two loads are combined to calculate the capacity of beams reinforced with *concrete jacketing*.

Flow Chart of Capacity Analysis of Beams with Concrete Jacketing Reinforcement System

This chart describes the steps in reinforcing the structure to overcome beam cracks. The first step is to collect the necessary project data and model the Pujasera building structure. After modeling, load calculations are carried out for coral, fertile soil, parks, and humans. This calculation aims to determine the shear forces and bending moments that cause cracks.

Once the cause is known, an efficient and economical retrofitting method is selected, namely *concrete jacketing*, which wraps the old structure with the new structure. This method was analyzed using applications such as SAP2000. After the analysis, a pre-design was carried out to determine the thickness of the beam and select a strong material for the *jacketing* process so that the crackingproblem would not occur again.

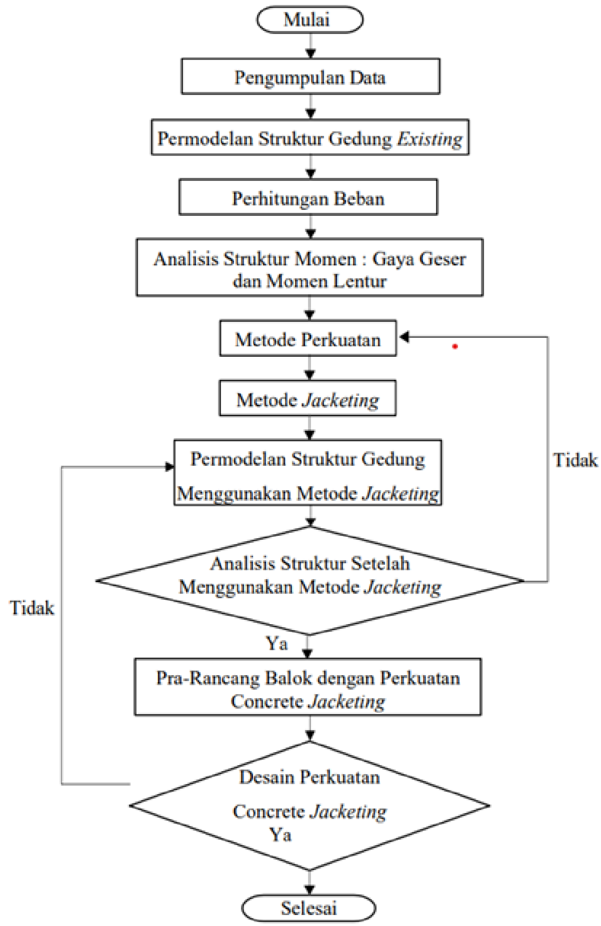

Figure 1. Research Flowchart

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Source: Thought Results.

Results and Discussions

Data Collection

Data collection is carried out to obtain the information needed in the case study; the data is obtained in the form of structural dimensions, the amount of structural reinforcement, and the quality used in the food court building. The data is obtained from analysis, data from the project, and data that has a national standard or SNI. The following data was obtained:

a. Beams

The following are the dimensions of the *jacketing* beam in the food court building:

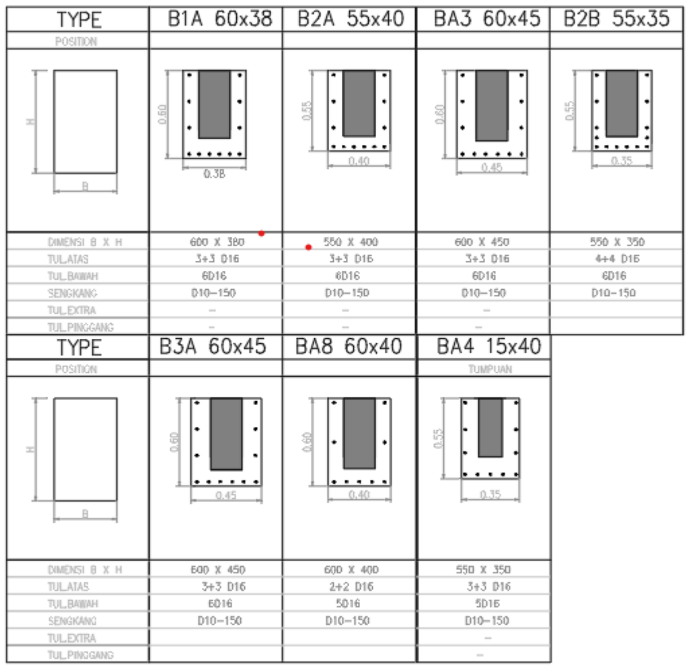

Figure 2. Beam Reinforcement

Source: Analysis Result

b. Columm

The following are the dimensions of the *jacketing* column in the food court building:

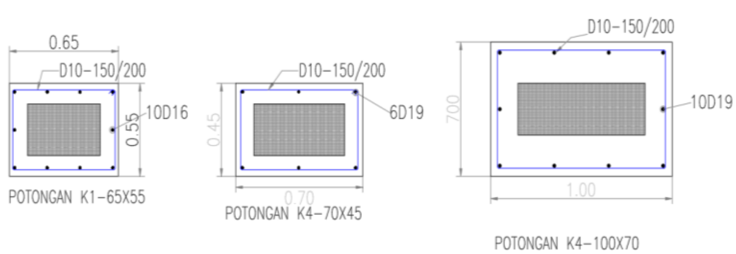

Figure 3. *Jacketing* Column Reinforcement

Source: Analysis Result

Modeling of *Existing* Pujasera Building Structure

Modeling is done to determine the capacity of existing structures. The known capacity is the loads that occur, whether they can be carried by the existing structure or not, and it is important to find out which structural parts have cracks due to the inability to carry the existing load. Structural modeling is done using the SAP2000 application. The advantage of SAP2000 is its ability to plan, analyze, and design complex structures. In addition, this application can also produce simulations and animations of structures that are very accurate and realistic. In modeling the existing building structure, load data is also needed so that it must be imported to find out the maximum load that occurs; these loads include:

a. live Load

The live load refers to the variable load that occurs during a structure's usage, particularly influenced by the building's activities and occupancy. According to SNI 1727: 2020, which specifies the minimum design loads and related criteria for buildings and other structures, the live load for buildings in the recreation area category is valued at 4.79 kN/m^2. This load value is incorporated into SAP2000 to function as an operational load for structural analysis, ensuring that the design meets the required safety and performance standards.

b. dead Load

The dead loads that occur on the food court building are as follows:

Table 1. Floor Plate Dead Load

No	Loads Incurred	Value	Unit
1	5 cm thick screed load	1,10	kN/m^2
2	Ceiling and suspender loads	0,22	kN/m^2
3	CNC ceiling plates and suspensions	0,41	kN/m^2
4	ME Installation Load	0,26	kN/m^2
5	Red brick ½ wall load	1,70	kN/m^2
6	Concrete table load	2,20	kN/m^2
Total Floor Plate Dead Load		5,89	kN/m^2

Source: Analysis Result

Table 2. Tilted Floor Plate Dead Load

No	Incurred Load	Value	Unit
1	Geotextile	0,28	kN/m^2
2	30 cm high coral	5,55	kN/m^2
3	Fertile soil 20 cm high	4,00	kN/m^2

4	Geocell	2,10	kN/m^2
Total Tilted Floor Plate Dead Load		11,93	kN/m^2

Source: Analysis Result

These loads are imported in Sap2000 as dead loads acting on the reinforced concrete structure. In the floor slab, the loading is divided in the vertical direction into 3 parts and the horizontal direction into 2 parts. The following is a picture of the load distribution in SAP2000:

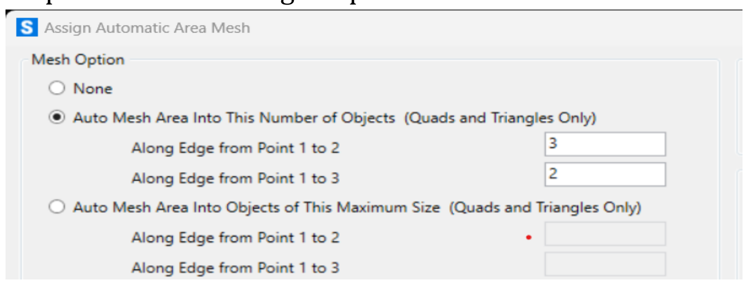

Figure 4. Automatic Area Mesh

Source: Analysis Results of SAP2000 Structural Analysis Application.

After the live load and dead load are known, the loading data is inputted on several bases, namely by knowing the risk category. Building structures are distinguished by risk categories determined based on the type of utilization of the structure. Structures that can be classified into more than one type of risk category must be planned based on the highest risk category. In addition to the table in SNI 1726: 2019 Procedures for Planning Earthquake Resistance for Building and Non-Building Structures, earthquake data is also needed at the Kediri City location, which can be seen on the RSA Cipta Karya website. The following earthquake data for the city of Kediri is based on RSA Cipta Karya:

```
Nama Kota             : kediri (B)
Bujur   / Longitude : 112.0147 Degrees
Lintang / Latitude  :  -7.8101 Degrees

Kelas Situs           : SD - Tanah Sedang

 PGA  = 0.392680 g
 PGAm = 0.474090 g
 CRs  = 0.000000
 CR1  = 0.000000
 Ss   = 0.844502 g
 S1   = 0.398812 g
 TL   = 20.000000 detik
 Fa   = 1.162199
 Fv   = 1.901188
 Sms  = 0.981480 g
 Sm1  = 0.758217 g
 Sds  = 0.654320 g
 Sd1  = 0.505478 g
 T0   = 0.154505 detik
 Ts   = 0.772524 detik
```

Figure 5. Design of Spektra Indonesia

Source: Spektra Indonesia Design Analysis Results.

Table 3. Response Spectrum Data

Time (sec)	Value (g)	Time (sec)	Value (g)	Time (sec)	Value (g)	Time (sec)	Value (g)
0,000	1,817	1400,000	2,508	3000,000	1,170	4600,000	0,763
0,050	2,700	1450,000	2,421	3050,000	1,151	4650,000	0,755
0,069	3,582	1500,000	2,340	3100,000	1,133	4700,000	0,747
0,104	4,465	1550,000	2,265	3150,000	1,115	4750,000	0,739
0,108	4,544	1600,000	2,194	3200,000	1,097	4800,000	0,731
0,139	4,544	1650,000	2,128	3250,000	1,080	4850,000	0,724
0,174	4,544	1700,000	2,065	3300,000	1,064	4900,000	0,717
0,208	4,544	1750,000	2,006	3350,000	1,048	4950,000	0,709
0,243	4,544	1800,000	1,950	3400,000	1,033	5000,000	0,702
0,278	4,544	1850,000	1,897	3450,000	1,017	5050,000	0,695
0,313	4,544	1900,000	1,847	3500,000	1,003	5100,000	0,688
0,347	4,544	1950,000	1,800	3550,000	0,989	5150,000	0,682
0,382	4,544	2000,000	1,755	3600,000	0,975	5200,000	0,675
0,417	4,544	2050,000	1,713	3650,000	0,962	5250,000	0,669
0,451	4,544	2100,000	1,672	3700,000	0,949	5300,000	0,663
0,486	4,544	2150,000	1,633	3750,000	0,936	5350,000	0,656
0,521	4,544	2200,000	1,596	3800,000	0,924	5400,000	0,650
0,537	4,544	2250,000	1,560	3850,000	0,912	5450,000	0,644
0,556	4,388	2300,000	1,526	3900,000	0,900	5500,000	0,638
0,590	4,130	2350,000	1,494	3950,000	0,889	5550,000	0,633
0,625	3,900	2400,000	1,463	4000,000	0,878	5600,000	0,627
0,660	3,695	2450,000	1,433	4050,000	0,867	5650,000	0,622
1000,000	3,510	2500,000	1,404	4100,000	0,856	5700,000	0,616
1050,000	3,343	2550,000	1,376	4150,000	0,846	5750,000	0,610
1100,000	3,191	2600,000	1,350	4200,000	0,836	5800,000	0,606
1150,000	3,052	2650,000	1,324	4250,000	0,826	5850,000	0,600
1200,000	2,925	2700,000	1,300	4300,000	0,817	5900,000	0,595
1250,000	2,808	2750,000	1,276	4350,000	0,807	5950,000	0,590
1300,000	2,700	2800,000	1,253	4400,000	0,798	6000,000	0,585
1350,000	2,600	2850,000	1,232	4450,000	0,789	----------	----------
1400,000	2,508	2900,000	1,210	4500,000	0,780	6000,000	0,585
1450,000	2,421	2950,000	1,190	4550,000	0,772		

Source: RSA Application Analysis Results

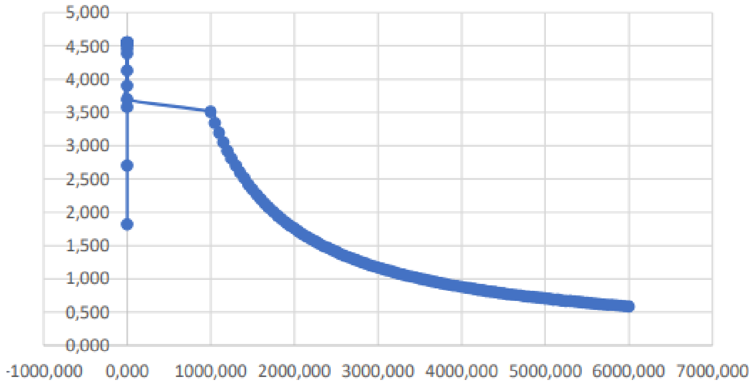

Figure 6. *Response Spectrum* Diagram

Source: Spektra Indonesia Design Analysis Results

From the above information sources, the following data is obtained:

Table 4. Earthquake Data

No	Symbol	X- axiz	Y- axiz
1	Location	Kediri	Kediri
2	S_1	0,399	0,399
3	S_s	0,845	0,845
4	S_{DS}	0,645	0,645
5	S_{D1}	0,505	0,505
6	T_L (sec)	20,00	20,00
7	Risk Category	II	II
8	I_e	1	1
9	C_d	5,5	5,5
10	Ωo	2,5	3
11	R	7	8
12	Tx (B-T) Nilai SAP2000	1,056	0,736
13	KDS	D	D

Source: Spektra Indonesia Design Analysis Results.

From the data table above, it can be concluded that the loading combination can be done as follows:

Sds = 0,654

ρ = 1,3 (kds D)

X Direction = 30%

Y Direction = 100%

Calculation of loading combinations used in response spectrum design.

(	1,200	+	0,200	Sds	)	DL	+	1,000	LL	±	ρ	0,300	Ex	±	ρ	1	Ey
(	1,200	+	0,200	0,654	)	DL	+	1,000	LL	±	1,300	0,300	Ex	±	1,300	1	Ey
(	1,200	+	0,131		)	DL	+	1,000	LL	±	0,390		Ex	±	1,300		Ey
	1,331					**DL**	**+**	**1,000**	**LL**	**±**	**0,390**		**Ex**	**±**	**1,300**		**Ey**

Table 5. Loading Combination

No	Combination Name	Loading Combination
1	Combination 1	1,4 D + 1,4 SW
2	Combination 2	1,2 D + 1,2 SW + 1,6 L
3	Combination 3.1	1,331D + 1,331 SW + 1,0 L + 0,390 Ex + 1,300 Ey
4	Combination 3.2	1,331D + 1,331 SW + 1,0 L + 0,390 Ex - 1,300 Ey
5	Combination 3.3	1,331D + 1,331 SW + 1,0 L - 0,390 Ex + 1,300 Ey
6	Combination 3.4	1,331D + 1,331 SW + 1,0 L - 0,390 Ex - 1,300 Ey
7	Combination 3.5	1,331D + 1,331 SW + 1,0 L + 1,300 Ex + 0,390 Ey
8	Combination 3.6	1,331D + 1,331 SW + 1,0 L + 1,300 Ex - 0,390 Ey
9	Combination 3.7	1,331D + 1,331 SW + 1,0 L - 1,300 Ex + 0,390 Ey
10	Combination 3.8	1,331D + 1,331 SW + 1,0 L - 1,300 Ex - 0,390 Ey

Source: Analysis Result

In combinations 3.1 to 3.8, Ex and Ey are taken from the x-direction and y-direction response spectrum data; data 3.1 to 3.8 also Ex and Ey can also be used in taking time history data. The following is the modeling of the Kediri City Square food court building:

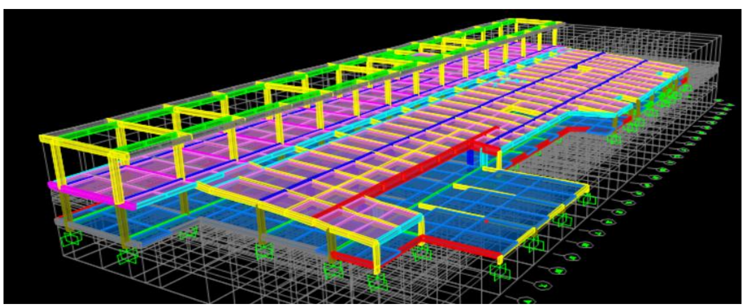

Figure 7. Modeling of the Food Court Building Structure
Source: Analysis Results

After modeling the food court building through the Sap2000 structural analysis application, *running* is then carried out; the purpose of *running* itself is to analyze the structure that has been modeled, enter the loads and forces acting on a building structure and run automatically the application which aims to determine the capacity of the structure, whether this *existing* structure is able to withstand the loads and forces acting or not so that it can find out the cause of the source of the cracks that occur. *Frames* that are unable to carry loads in SAP2000 are red, usually found in column and beam structures, which are the main structures that hold and distribute working loads. Here is the picture after *running*.

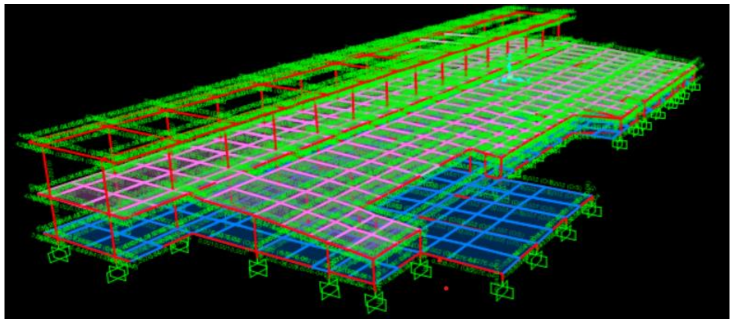

Figure 8. Structure modeling after running

Source: Analysis Results from SAP2000.

From the picture above, several parts of the structure are red, which means that the structure is less able to carry the working load; in this case, it is necessary to trace which *frames* are the same and how many red *frames*, the following is the number of red frames

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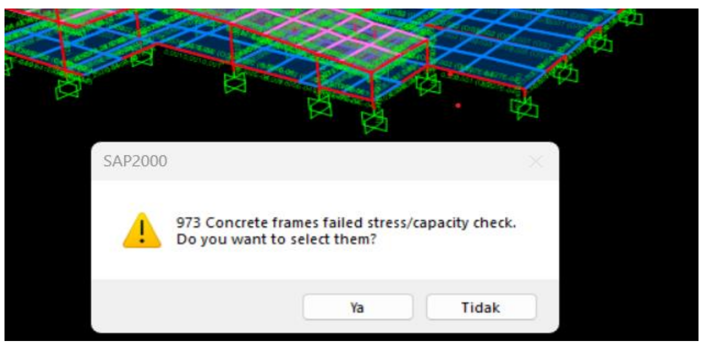

Figure 9*.* Checking the Pujasera Building Structure

Source: Analysis Results from SAP2000.

In the picture above, information is that some 973 structural frames cannot carry the load that occurs or beyond the limits of the structure itself. After that, check the forces that work. The following is a picture of the forces acting in the structure of the food court building

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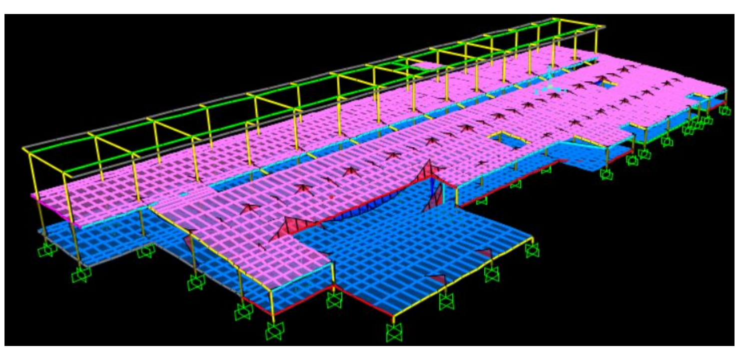

Figure 10. Checking the Working Style in the Pujasera Building Structure
Source: Analysis Results from SAP2000.

In Figure 10, several forces work, which are quite large, especially in the beam area, which has a span of 15 meters. As in the picture below.

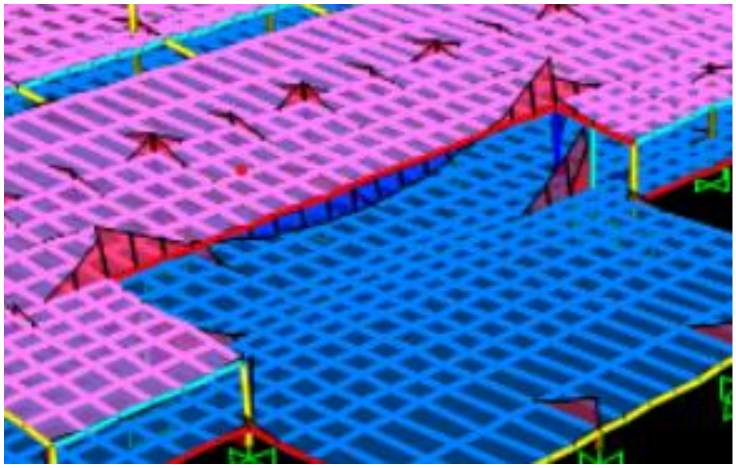

Figure 11. Checking the Structure Style
Source: Analysis Results from SAP2000

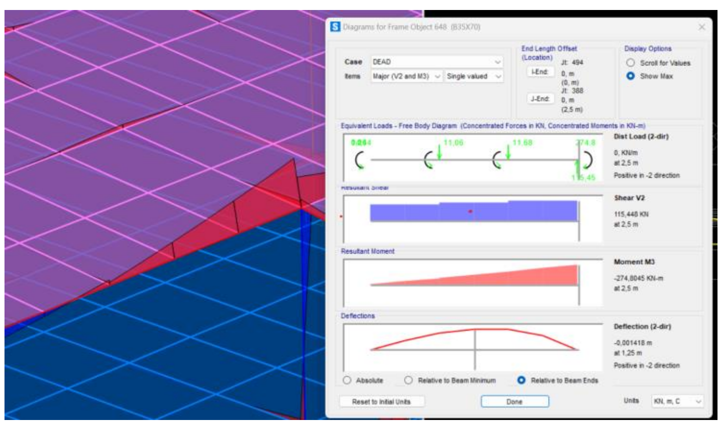

Figure 12. Checking the forces acting on the structure
Source: Analysis Results from SAP2000.

From the analysis of the existing building structure, it can be concluded that the structure cannot withstand the loads that occur, causing cracks in each *frame*/ building structure.

Reinforcement Method for Pujasera Building Structure

From the explanation in the previous chapter, the method that is easy and often done is the concrete *jacketing* method. This method is done by adding/thickening the *existing* structure by reinforcing iron and casting around the *existing* structure or wearing a jacket. From the modeling of the existing building structure, modeling is carried out using the SAP2000 application, such as modeling on the existing building; the difference this time is checking the structure that has been jacketed. The results of the *jacketing* process are quite satisfactory namely the frame, which was originally unable to withstand the working load after *jacketing; the frame* becomes capable of withstanding the working load, following the results of checking the structure after concrete *jacketing*.

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Figure 13. Checking the Strength of the Structure After Reinforcement

Source: Analysis Results from SAP2000.

From the jacketing results, several frames are enlarged; the following types of structures are carried out in jacketing:

Table 6. Concrete jacketed structures

Structure Type	Notas	Dimensions
Column	K1 K3 K4	650 x 550 mm 1000 x 700 mm 700 x 450 mm
Beams	B1A B2A BA3 B2B B3A BA4 BA8	600 x 400 mm 550 x 400 mm 450 x 300 mm 550 x 350 mm 600 x 450 mm 500 x 350 mm 600 x 400 mm

Source: Analysis Result

After jacketing the column and beam structure, modeling is carried out using the SAP2000 application. The following modeling is designed according to the cracked structure.

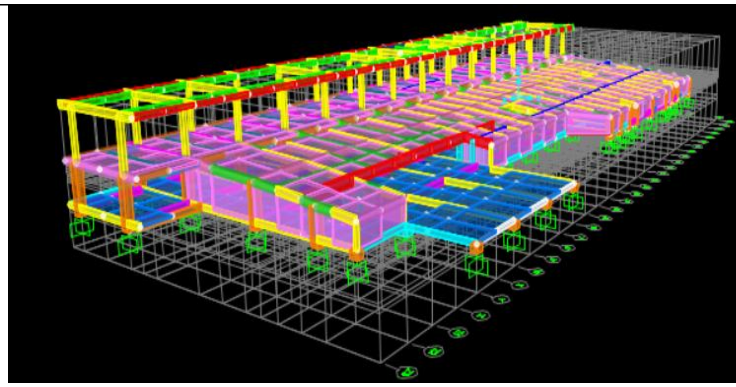

Figure 14. Modeling of Strengthening the Pujasera Building Structure
Source: Analysis Results from SAP2000.

In Figure 14, some of the dimensions of the columns and beams are enlarged due to the concrete jacketing. After modeling, run the building that has been done with concrete jacketing.

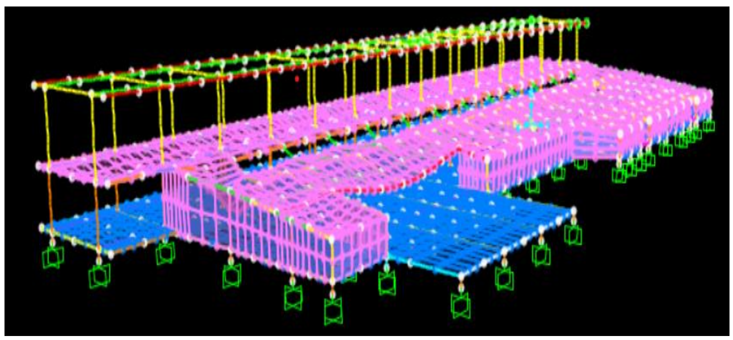

Figure 15. Load Checking After Strengthening the Structure
Source: Analysis Results from SAP2000

After *running*, the loads are working on the structure of the food court building. Then, check the loads and forces that work.

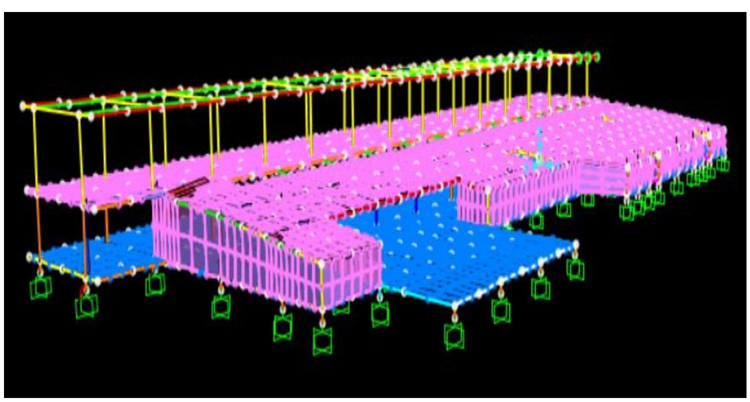

Figure 16. Checking the Force After Strengthening the Structure
Source: Analysis Results from SAP2000.

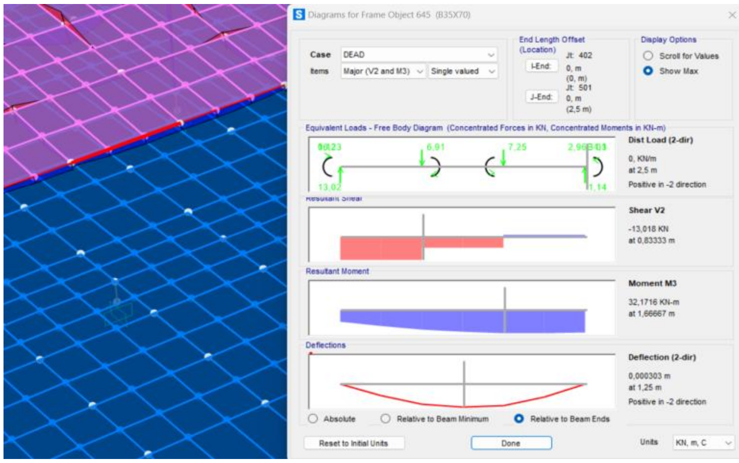

Figure 17. M3 Moment Magnitude

Source: Results of Analysis from SAP2000.

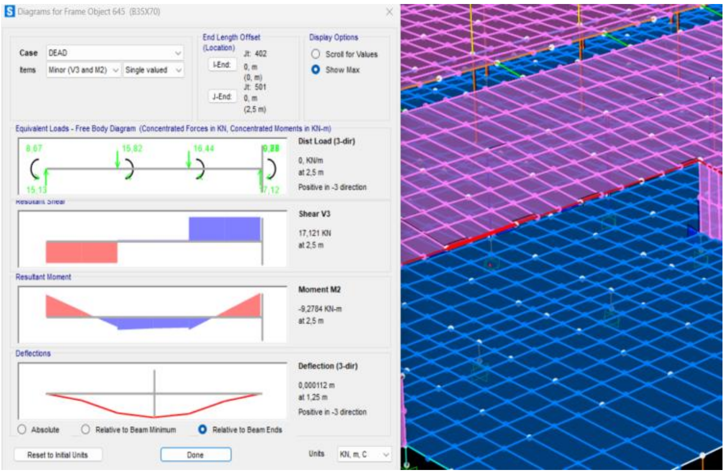

Figure 18. Shear magnitude V3

Source: Analysis Results from SAP2000.

In the forces that work after *running, the* results occur in balance in the moments and shear forces that work so that neither moment nor shear forces are so large. Furthermore, checking the structure that has been carried out by concrete *jacketing* is carried out, the purpose of the check is to find out the results that come out so that they are used in the right repair method according to repair standards and are not carried out carelessly and cause material / non-material losses and avoid casualties. The following are the results of checking information on structures that have been carried out concrete *jacketing*.

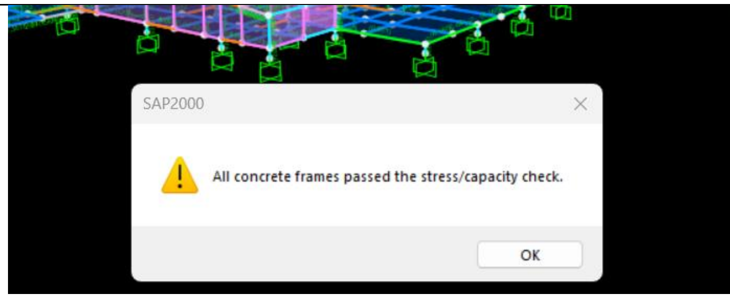

Figure 19. Information on Checking the Structure After Reinforcement
Source: Analysis Results from SAP2000.

After checking it turns out that the structure of the food court building is able to withstand the load or force at work. In the check, there is clear information that each building structure is able to withstand the load or capacity is met.

In this case, the reinforcement system in concrete jacketing can be used and is able to withstand the shear forces and bending moments that occur in the structure of a building. In addition to the forces at work, it is also able to bear the loads that work on the food court building. The difference in moment and axial forces can be seen in table 7.

Table 7. Comparison before and after *jacketing*

No. Frame	Sebelum *Jacketing*		Sesudah *Jacketing*	
	Momen	Gaya Axial	Momen	Gaya Axial
Balok B5X70 (641)	103,5793 kN-m	-69,323 kN	26,9994 kN-m	16,782 kN
Kolom K4 (960)	-15,944 kN-m	-400,192 kN	10,5871 kN-m	-449,231 kN
Kolom K1 (860)	-11,9081 kN-m	-400,396 kN	15,3892 kN-m	-373,337 kN
Kolom K2 (985)	14,8315 kN-m	-1,687 kN	1,0005 kN-m	0,122 kN

Source: Analysis Results from SAP2000.

Data table 7 is not always after jacketing the value of the moment and axial force is above zero, there are some whose value is below zero but this does not cause problems because the load is assisted by the column and sloof structure. So that it makes a unit that is able to withstand the working load.

Conclusion

The conclusions drawn from the case study of the food court building are as follows: Based on the structural analysis results, several structural frames were found to be incapable of withstanding the applied loads and forces, resulting in significant cracks. By using the concrete jacketing method to strengthen the structure, there was an increase in the load-bearing capacity, making the structure capable of handling the applied loads and forces, as illustrated in Figure 19. There was also an increase in the axial force on frame number 641 of the B35x70 beam structure, from -69.323 kN before jacketing to 16.782 kN after jacketing, and an increase in the moment force on frame number

860 of the K1 column structure, from -11.9081 kN/m before jacketing to 15.3892 kN/m after jacketing, as shown in Table 7.

Based on the results of this case study, several suggestions are provided: The research can be continued or further analyzed in cases where structural cracks are present in bridges. Future analyses should consider using alternative methods for structural analysis, either manually or through computer programs, and examine aspects related to age variations or methods for accelerating concrete drying.

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