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STRENGTH ANALYSIS OF FORMWORK USING FALSEWORK FLYING SYSTEM ON SLAB-ON PILE STRUCTURE

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Abstract: The Semarang-Demak Toll Road was planned with detailed procedures to address disorganized road networks, increased traffic volumes, congestion, land subsidence, and tidal floods. It has toll entrances in Semarang, Genuk, and Sayung sub-districts and ends in Demak City. Its purpose is to minimize traffic jams, provide access to tourist cities, and serve as a tidal barrier sea embankment. The formwork support system's proper design is crucial to ensure the safe construction of the main structure. A unique disk lock and steel tubular scaffold are utilized for a slab-on-pile structure employing a flying falsework system. This approach results in a structurally sound and secure construction that is not susceptible to twisting, providing quick erection and disassembly, significantly improving construction efficiency. The system was employed in a portion of the Semarang-Demak toll road project, and its efficacy was evaluated using finite element analysis software. The software provides security and convenience in analyzing structures, paying attention to the nominal strength of each steel profile and the internal forces at work. All components are safe as their actual deflection falls within the maximum limit.

Keywords: finite element, analysis, formwork

ИССЛЕДОВАНИЕ ПРОЧНОСТИ ОПАЛУБКИ С ПРИМЕНЕНИЕМ ПОДВЕСНОЙ СИСТЕМЫ ДЛЯ ПЛИТНО-СВАЙНОЙ КОНСТРУКЦИИ

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Аннотация: Платная дорога Семаранг – Демак была запроектирована с учетом подробных процедур, имея целью решение проблем хаотичной дорожной сети, увеличения интенсивности движения, дорожных заторов, просадок грунта и приливных водных потоков. Он имеет платные въезды в подрайоны Семаранг, Генук и Саюнг и заканчивается в городе Демак. Его цель — минимизировать дорожные пробки, обеспечить доступ к туристическим городам и служить приливно-отливным барьером для морской набережной. Правильная конструкция системы опирания опалубки имеет решающее значение для обеспечения безопасного строительства основной конструкции. Для конструкции «плита-на-сваях» с использованием системы подвесных опалубок используются уникальный дисковый замок и стальные трубчатые леса. Такой подход позволяет получить конструктивно прочную и надежную систему, не подверженную скручиванию, обеспечивающую быстрый монтаж и демонтаж, значительно повышая эффективность строительства. Система использовалась в рамках проекта платной дороги Семаранг – Демак, ее эффективность оценивалась с помощью программного обеспечения для анализа методом конечных элементов. Программное обеспечение обеспечивает безопасность и удобство анализа конструкций с учетом номинальной прочности каждого стального профиля и действующих внутренних сил. Все компоненты безопасны, поскольку их фактическое отклонение находится в пределах максимального предела.

Ключевые слова: конечный элемент, анализ, опалубка

INTRODUCTION

The development of toll roads in Indonesia has experienced significant progress and quality improvement [1]. The construction of toll roads itself is a form of effort by the government to help the Indonesian people carry out activities that require the mobilization of goods or

services, in economic or economic terms, well and short.

Semarang is the capital of Central Java, with high economic growth. This growth can be seen in new industrial buildings, residential areas, and the expansion of city areas. This development also results in problems such as disorganized road networks and increasing traffic volumes, which cause congestion. Changes in land use result in the absorption area being reduced, causing land subsidence and tidal floods [2].

It was planned to build a toll road under detailed and thorough planning procedures, namely the Semarang-Demak Toll Road, which is integrated with the Semarang City Sea Embankment. With this plan, it is hoped to overcome the congestion problem due to the increase in vehicle volume on the Semarang-Demak highway and the sea embankment, which is expected to overcome tidal floods in the Semarang coastal area [3]. The Semarang-Demak Toll Road Project, which stretches from West to East, is part of the Toll Road system connecting the city of Semarang and the city of Demak. This toll road has a length of 27 km, which is divided into two packages. Package 1 is planned to start from Semarang to Sayung, which has a length of 10.69 km. Package 2 is planned to start from Sayung to Demak, which has a length of 16.31 km. The toll entrance is located in the Semarang, Genuk, and Sayung sub-districts, which end in Demak City [4].

The function of the Semarang-Demak toll road is to minimize traffic jams on the Semarang-Demak-Surabaya north coast route and also to get to tourist cities in Demak, namely the Kadilangu/Sunan Kalijaga Tomb and the Great Mosque of Demak, as well as to overcome existing tidal floods along the north coast as a tidal barrier sea embankment [5].

PROJECT CONDITIONS

The condition in the area Project Development Road Toll Semarang Demak STA 10+394 up to STA 27+000, Which length is around 16.31 km, dominated by rice fields and swamps. Land base from project This Also has characteristics that are very soft to a depth of about 30 m below the existing surface. Due to the depth of the soil, the heap's limitation is from the H-Critical factor. An Embankment with PVD Preloading soil improvement treatment cannot accommodate a finish grade that is too high. Thus, a Slab-on Pile structure is needed to meet the need for road Finish Grade [6].

A slab on a pile is a slab structure that stretches between piles. This structure is suitable for roads with high Finish Grade designs and cannot accommodated by heap land customary. Structure This consists of Pile, Pile Heads, and Decks Slabs.

The following is a typical slab-on-pile design and work map:

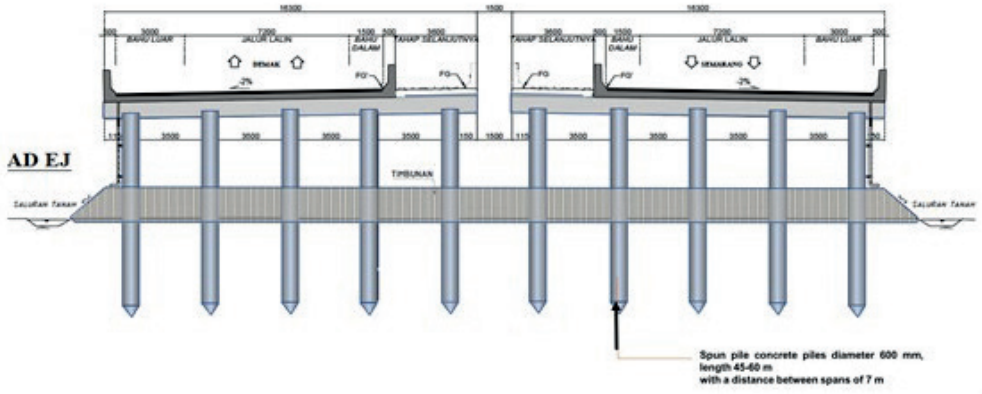

Figure 1. Slab On Pile Structure

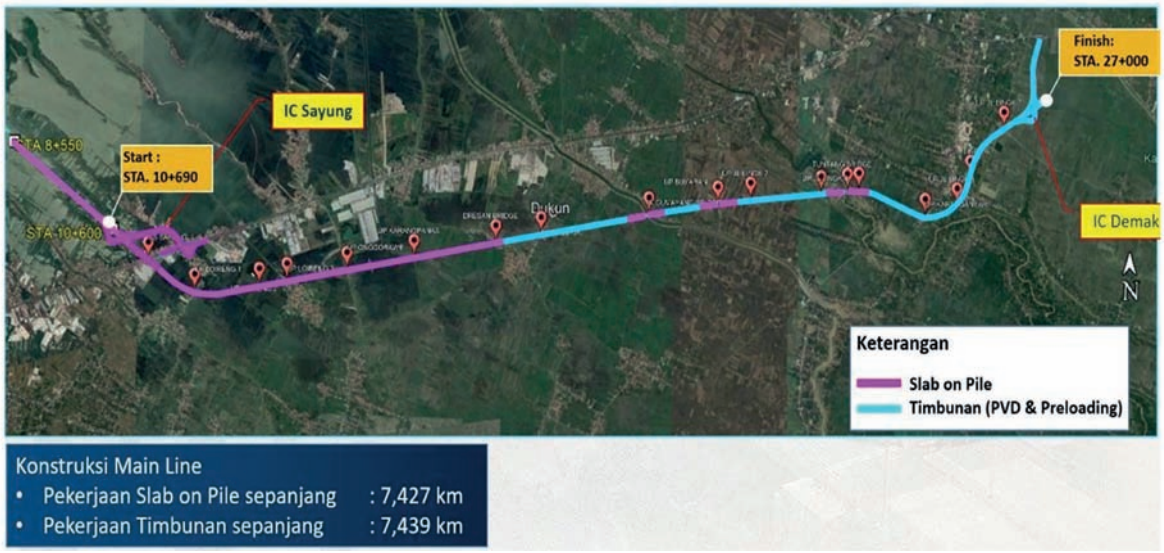

Figure 2. Scope of work for Slab On Pile

FLYING FALSEWORK SYSTEM FORMWORK

Shoring System (Scaffolding)

In making a building element using reinforced concrete as the primary material, a mold is needed so that the reinforced concrete takes the same shape desired element. The mold in question is formwork [7]. Slabs on roads, toll roads, or bridges usually use formwork supported by scaffolding because this work is done at a height. Scaffolding will withhold heavy Alone from formwork, And concrete bony ones that will cast.

The shoring system is a slab formwork system that uses a series of scaffolding, which is used to support the deck slab formwork [8] when casting concrete. The scaffolding needed to support the formwork is usually quite a lot. Apart from that, the support of this scaffolding is the subgrade.

Flying Falsework System

Based on geotechnical investigations in the Semarang-Demak 2 STA 10+690 – 27+000. The soil conditions are in the dominant line of clay soil, so the soil's carrying capacity is relatively low. In making formwork supported by scaffolding, it is necessary to prepare firm scaffolding ground to accommodate the load from the formwork and concrete, which will set a land base [9]. It needs time A relatively long. Apart from that, much scaffolding material is needed to make formwork matter. It usually Can overcome with processing slab per segment, so there is work on dismantling and re-installing scaffolding and formwork. However, the problem is that disassembly and installation take a long time. Therefore PT. PP made an innovation, namely Flying Falsework (Formwork Flying).

Flying Falsework is formwork for slab casting. This formwork uses steel material, which is arranged in such a way. This formwork hangs between the pile heads. Load from casting and weight from formwork will detained by the pile head. So that place Which needed will less And need setup land base For tool heavy Which Also.

The following is a 3D design of formwork [10] with a flying falsework system :

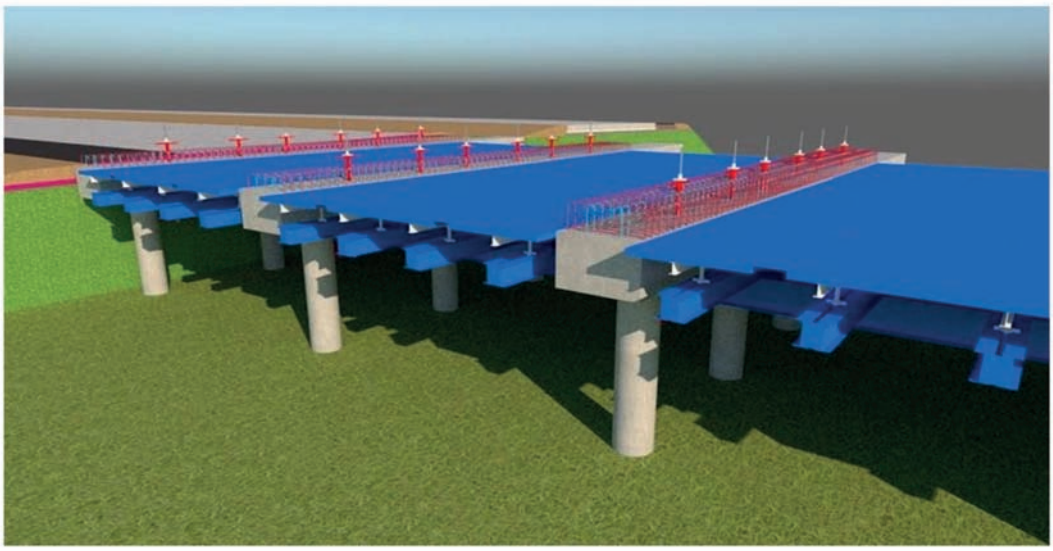

Figure 3. Flying Falsework 3D Rendering

Advantages of Flying System Formwork Falsework

In making a slab, scaffolding is needed to support the formwork from the slab (shoring method), which rests on the subgrade. The subgrade soil in constructing the Semarang Demak toll road has characteristics that are not strong enough to be used as a footing. Therefore, slab formwork using a flying falsework system is used. The following are the advantages of the flying falsework formwork system in terms of cost, quality, and time [11].

Flying Falsework Formwork System has advantages in terms of cost, namely that it is expensive at the start but cheap during implementation [12]. Due to high costs, elicitation material steel For structure flying falsework. However, because the structure slab on the pile Is very long, so far, 9.56 km, the use of costs will be more efficient when compared to using scaffolding.

The use of the shoring method requires a firm base soil. In case subsidence occurs, land consequence burden from implementation work deck slabs, so results from the deck slab will be deflection. So the quality provided could be better [13].

Concrete deck slabs on flying falsework structures will have minimal deflection if using a flying falsework system because the support is directly dependent on the pile head. Therefore, the work will be more precise with maximum results.

Using flying falsework formwork has the advantage that the formwork series can reach 3-5 spans on a slab or pile. Compared to the shoring method, which can only have a maximum of one formwork span due to the large amount of scaffolding required for one span [14]. So, the time used for slab casting will be faster than the shoring method.

The proper design of the formwork support system is paramount to ensure the safe construction of the main structure. A unique disk lock and steel tubular scaffold are utilized for a slab-on-pile structure utilizing a flying falsework system to establish a stable connection between members in multiple directions. This approach results in a structurally sound and secure construction that is not susceptible to twisting. Furthermore, the formwork support system provides quick erection and disassembly, significantly improving construction efficiency. Given these benefits, this system is widely employed in formwork support. The formwork support system was leveraged in a portion of the Semarang-Demak toll road project, and its efficacy was evaluated using finite element analysis [15] software SAP2000.

MATERIAL & MODEL

Material

The materials used for flying falsework work are as follows:
Steel Grade A36
Material Properties of Steel Grade A 36 are as follows:
E = 200000 MPa
$F\,y$ = 240 MPa
$F\,u$ = 400 MPa
The steel used for flying falsework formwork has the following dimensions:
a. WF 300.150.6,5.9 Double
The WF 300.150.6,5.9 Double steel profile is used as a support that depends on the PT Bar.

Figure 4. WF 300.150.6,5.9 Double

b. WF 150.75.5.7
WF 150.75.5.7 steel profile directly supports 6mm plates for slab formwork.

Figure 5. WF 150.75.5.7 (before installation)

Figure 6. WF 150.75.5.7 (After installation)

c. HB 350.350.12.19
HB 350.350.12.19 Steel Profile is used as a longitudinal connector placed on a WF 300.150.6,5.9 Double support.

Figure 7. HB 350.350.12.19

d. 6 mm plate and UNP 80
Steel plates are used to support the slab to be cast directly, with a plate steel thickness of 6mm And supported with a configuration.
UNP 80 steel to increase the stiffness of the steel plate. This steel plate has an area per segment of 3.5 m x 1.5 m.

Figure 8. 6mm Steel Plate

e. Jack U Head

The U Head Jack is used to adjust the slope and elevation of the steel plate. So, the slab shape can be adjusted using the U-Head Jack.

Figure 9. U Head Jack 50mm

PT BAR Grade 830/1030

Material Properties of PT BAR Grade 830/1030 are as follows:

E = 200000 MPa

$F\,y$ = 830 MPa

$F\,u$ = 1030 MPa

PT Bar D32 is used as a support hung on the pile head. This jack is inserted into the pile head via a sparing pipe and then locked on the pile head.

Figure 10. PT Bar D32

Figure 11. Sparing Pipe

Figure 12. PT Bar Washing at Pile Head

Modeling Material SAP 2000 Software

The following is the material modeling of the FalseWork Flying Formwork:

a. Steel Grade A36

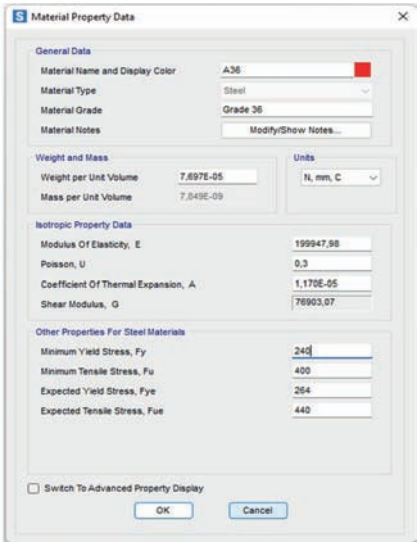

Figure 13 A36 Steel Modeling

b. PT BAR

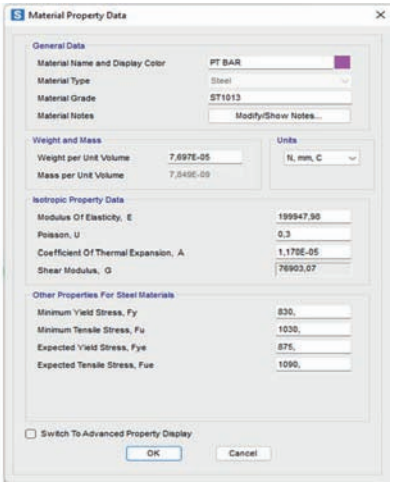

Figure 14. PT BAR 830/1030 Steel Modeling

Section Modeling Properties

The following is the modeling of the steel structure used in the formwork:

a. HB 350.350.12.19

Figure 15. Modeling HB 350.350.12.19

b. HB 350.350.12.19 Double

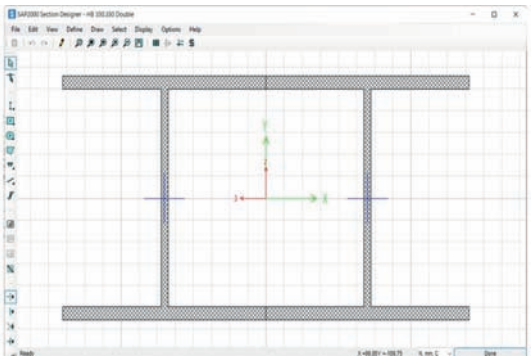

Figure 16. Modeling HB 350.350.12.19 Double

c. WF 300.150.6,5.9 Double

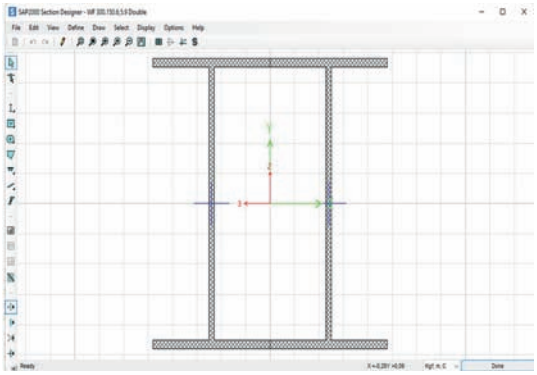

Figure 17. Modeling WF 300.150.6,5.9 Double

d. WF 150.75.5.7

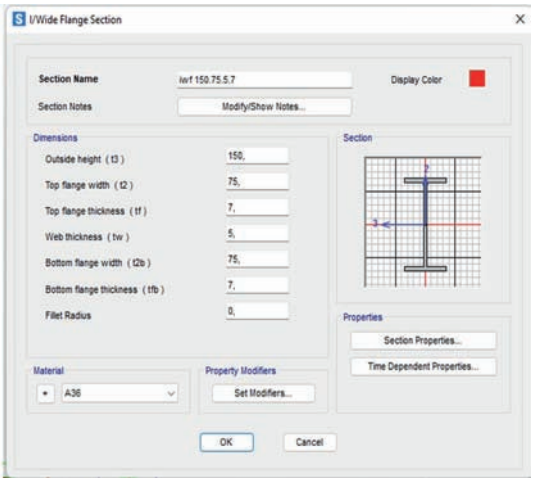

Figure 18. WF Modeling 150.75.5.7

e. UNP 80

Figure 19. UNP 80 Modeling

f. UNP 80 Double

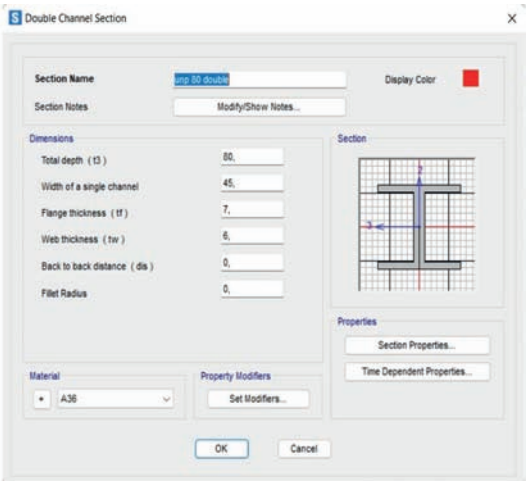

Figure 20. Modeling UNP 80 Double

g. Jack U Head 50 mmm

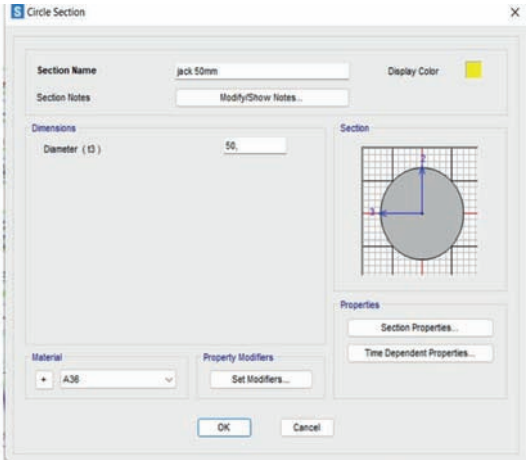

Figure 21. 50 mm U Head Jack Modeling

h. Steel Plate 6 mmm

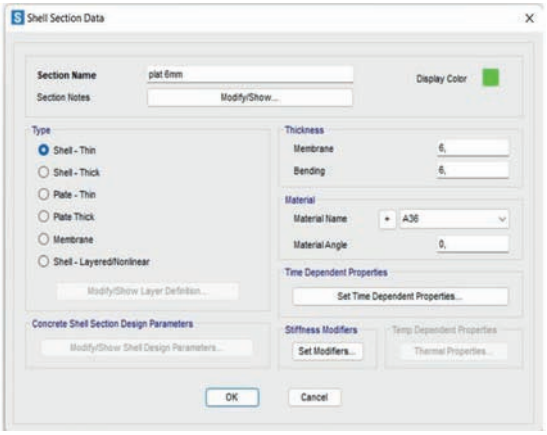

Figure 22. Modeling of 6 mm steel plate

i. PT BAR 32

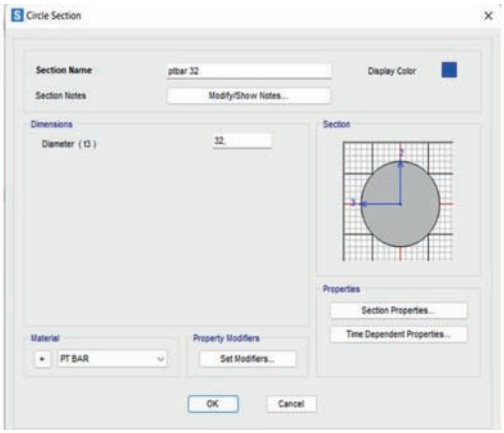

Figure 23. Modeling PT BAR 32 mm

Load Pattern and Load Combination

a. Input Load Patterns

In the SAP2000 program, several load patterns are included in the table below:

Table1. Definition of load pattern

Load Pattern	Definition
D.L	Dead load that has been modeled in SAP2000 (ex: IWF Beam, Steel Plate)
SIDL	Additional dead load (example: Fresh concrete, Reinforcing Steel)
LL	Living Expenses (ex: Worker Expenses)

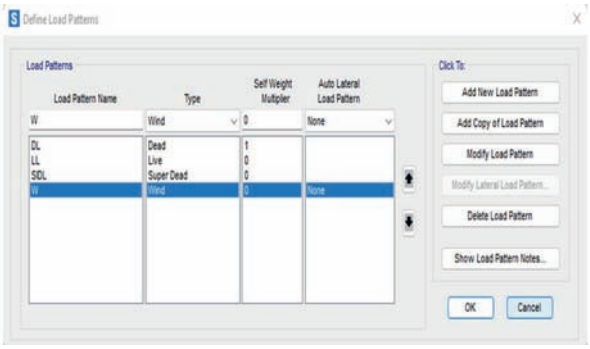

Figure 24. Define load pattern

b. Input Load Combination

On modeling structure slats system flying falsework used Loading combinations are as follows :
1. 1.4 D
2. 1.2 D + 1.6 LL
This combination is based on SNI 1727:2020 concerning Minimum Loads on Buildings[16]. The following is the load combination input in the SAP2000 program:
a. 1.4 D

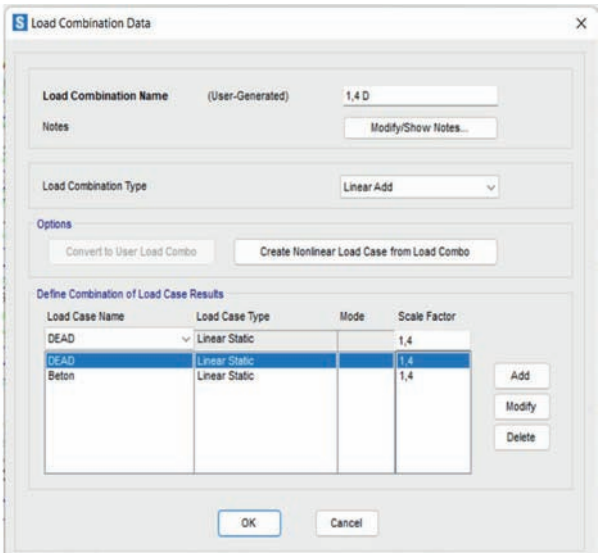

Figure 25. 1.4 D combination

b. 1.2 D + 1.6 LL

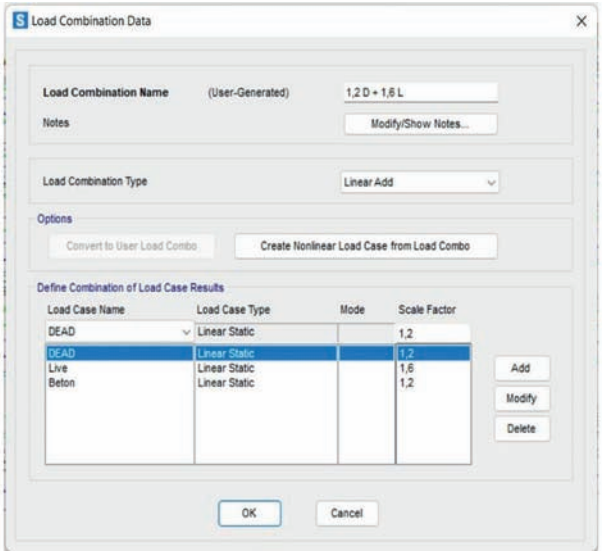

Figure 26. Combination 1.2 D + 1.6 LL

c. Envelopes
The envelope is used to find the most significant force on each element in SAP2000 based on the load combination that has been entered.

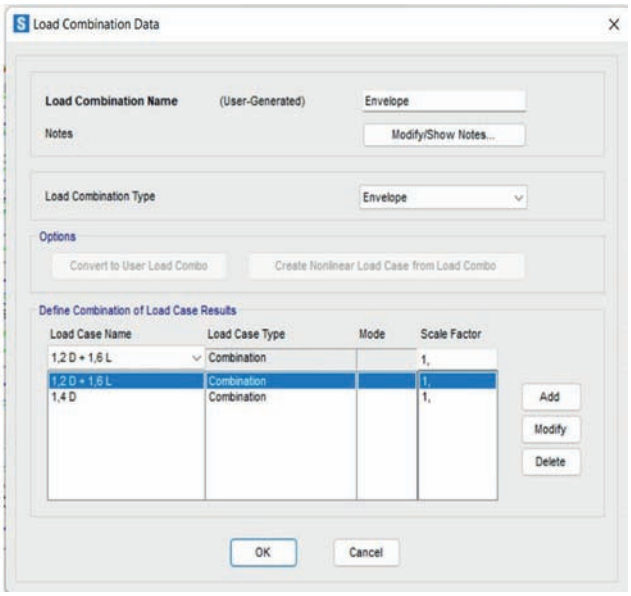

Figure 27. Envelope combination

The formwork frame is modeled according to the approved shop drawing. Modeled from PT Bar Hanger, WF 300 Hanger Beam Double, Beam Transverse HB 350,350, Beam Elongated WF 300 double, Beam support WF 150.75 to Jack U Head and Floor Plate steel.
The UNP frame modeling is more superficial than that in the shop drawing because the UNP function in this modeling only distributes the construction load to the mainframes. The modeling is made into 5 Slab on Pile spans (5 x 7m) to represent the analysis of internal forces in the middle and edge spans.
Modeling formwork flying falsework need to give a linear link on a number of the meeting point between the rods so that the load distribution works correctly and as expected. Below is the linear link modeling and formwork structure modeling with the entire flying falsework system in the SAP 2000 program :

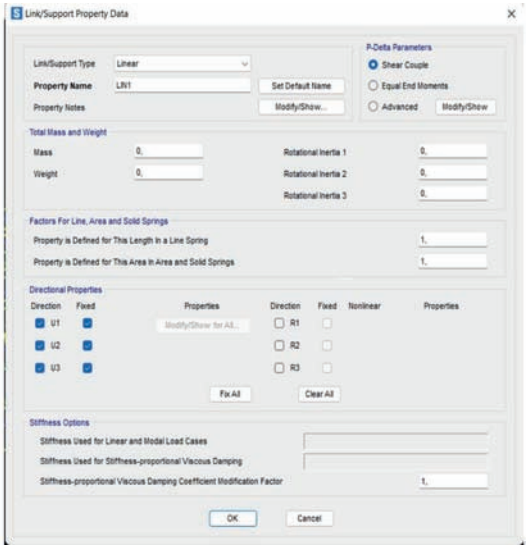

Figure 28. Linear link modeling

Loading

Load, Which happens in structure formwork systems flying falsework, consists of additional dead loads from fresh concrete and loads from workers and tools. The value of the imported load can be seen from the calculation below.

a. Dead Load

$q\ SIDL$ = Thick × **γ** concrete
= 0.35 × 2690
= 941.5 kg/m 2

b. Life

$q\ LL$ = 250 kg/m 2

The load above is input to the steel plate as a load evenly distributed over the area.

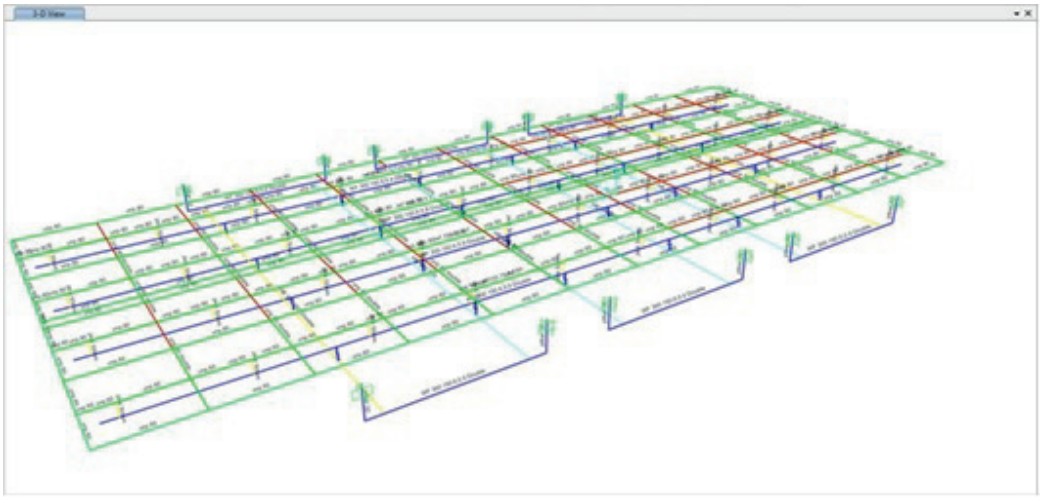

Figure 29. Overall modeling

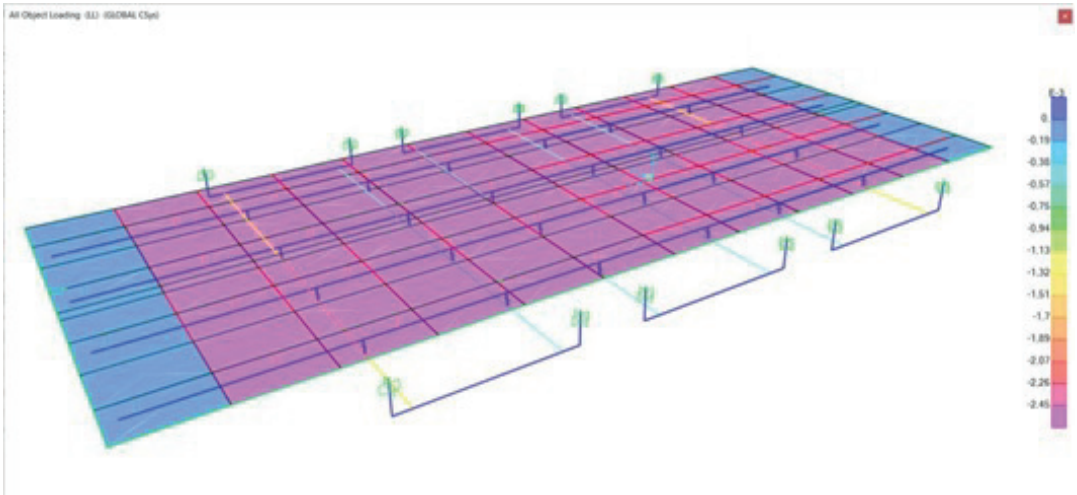

Figure 30. Loading are

RESULTS AND DISCUSSION

The analysis provides security and convenience output from modeling with SAP 2000 software.

a. Security Controls Structure

The structure modeled in SAP2000 software is analyzed by paying attention to the nominal strength of each steel profile with the internal forces that will work. If the ratio between these two things is below the value 1, the structure is strong enough to withstand the working load. In the results of the analysis Figure 31, it can be seen that all profiles have a capacity ratio below 1. Therefore, the structure is safe and robust enough to withstand the existing load.

b. Deflection Control Structur

The deflection limits that pertain to steel structures utilized in building construction are in accordance with SNI 1729:2020 [16]. As per the prevailing standards of the industry, the deflection limit that applies to standard beam components is set at L/240 (see Table 2).

The software SAP 2000 provides both security and convenience in analyzing structures. Analyzing the structure modeled in SAP2000 software involves paying attention to the nominal strength of each steel profile and the internal forces at work. If the capacity ratio of a profile is below 1, it means the structure is strong enough to withstand the existing load. Figure 31 shows the capacity ratio of each profile, and it is evident that all profiles have a capacity ratio below 1, meaning the structure is safe and robust.

Table 2. Deflection limit controls

No	Structural Components	Location	L (mm)	Max Deflection (mm)	Actual deflection (mm)	Status
1	Longitudinal Beam	Middle of Span	3000 (edge)	12.5	8.73 (edge)	Safe
2	Longitudinal Beam	Span Edge	7000 (mid) 3000 (edge)	29.1 12.5	5.6 (mid) 7.8 (edge)	Safe
3	Transverse Beam	Middle of Span	3500	14.5	2.8	Safe
4	Transverse Beam	Span Edge	3500	14.5	8.6	Safe

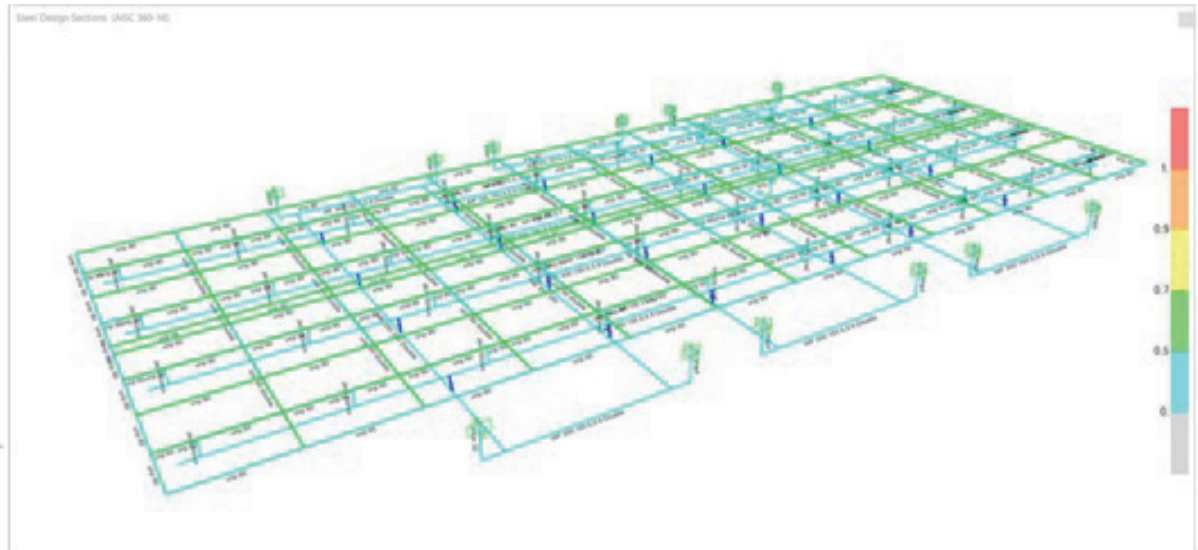

Figure 31. Structure capacity ratio

CONCLUSION

The software for analyzing structures with the SAP 2000 is an excellent tool that provides security and convenience. To ensure proper analysis of the structure modeled in SAP2000 software, it is essential to consider the nominal strength of each steel profile and the internal forces at work. If the capacity ratio of a profile is less than 1, it indicates that the structure can withstand the existing load. Fortunately, all profiles have a capacity ratio below 1, meaning the structure is safe and robust.

As per SNI 1729:2020 Steel Structure Planning for Buildings, for regular beam structural components, the deflection limit is L/240. This limit controls different structural components, including longitudinal beams, transverse beams, and their locations, maximum deflection, actual deflection, and status. Fortunately, all components are safe, as their actual deflection falls within the maximum limit. This implies that the structure is strong, and all its components can withstand all the internal and external forces.

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