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Tanjung Pura interchange bridge pillar analysis based on SP colomn value

Gede Suartana[1*], I Nengah Sinarta[1], I Wayan Gde Erick Triswandana[1]

[1] *Department of Civil Engineering, Warmadewa University, Denpasar, 80235, Indonesia*
[*] suartana103@gmail.com

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ABSTRACT

The Tanjung Pura interchange overpass bridge, a critical connector road on the Trans Sumatra Toll Road, currently utilizes wall-type pillars that have limitations in seismic performance and construction efficiency. This study aims to redesign the bridge pillars from a wall-type to a portal-type configuration to improve structural safety and optimize the design. The redesign process involves several key steps, including data collection through literature review and documentation from project stakeholders, structural modeling using SAP2000 v.20 software incorporating the redesigned portal-type pillars with optimized dimensions and reinforcement arrangements, load analysis considering various load combinations based on Indonesian bridge design codes and standards, and capacity evaluation using SP Column v.7 software to assess the structural adequacy and safety of the redesigned pillars. The portal-type pillars, with dimensions of 1500 mm × 2500 mm and 50D32 main reinforcement, along with additional leg reinforcement in the plastic hinge regions, demonstrated improved seismic performance and constructability compared to the original wall-type design, with a maximum capacity ratio of 0.20 indicating sufficient reserve capacity and safety margin. The successful redesign of the Tanjung Pura interchange overpass bridge pillars highlights the potential for optimizing bridge structures to enhance safety, efficiency, and economy, serving as a valuable reference for future bridge rehabilitation and redesign projects.

Keywords: bridge pillar redesign; portal-type pillars; capacity evaluation

1 Introduction

The Trans Sumatra Toll Road is an infrastructure project that is planned to connect the end to the tip of Sumatra Island from Lampung to Aceh with a planned road length of around ±2,735 km which is divided into several sections and sections and zones where, the sections are pieces per toll road destination, while the sections and zones are the division of the work area of the section. On each toll road section, there is a place to end the destination or start the journey by switching to the interchange which will lead to the toll exit booth, as well as to the main toll road main road. To make the switch to the interchange that intersects the main road, there is a structural building that plays an important role in connecting the intersection of the transition road, namely the overpass bridge structure building.

A bridge is a structure that crosses the road across all obstacles below without closing it [1]. Such as the Tanjung Pura interchange overpass bridge built on the main toll road main road with a function as a connecting road for the transition from the main road to access in and out of the toll road. The construction of this overpass bridge is needed because the transition lane intersects the main road or this overpass bridge is right on the interchange which can be interpreted as an interchange that connects one road to another without the need to stop first.

The Overpass Bridge building on the toll road interchange plays a very important role in the transition, with the placement of abutments and pillars and girders that span over the toll road. The design of the building plan concept has been calculated from the data in the building planning. However, the initial design of the Tanjung Pura interchange overpass bridge utilized wall-type pillars, which have certain limitations and potential issues.

Wall-type pillars, while commonly used in bridge construction, have several drawbacks. Firstly, they are more susceptible to seismic forces due to their rigid nature and limited ductility [2]. In the event of a strong earthquake, wall-type pillars may experience significant damage or even failure, compromising the safety and stability of the entire bridge structure. Secondly, wall-type pillars often require a larger footprint and more materials, leading to higher construction costs and environmental impact [3].

To address these concerns, the author proposes redesigning the wall-type pillars of the Tanjung Pura interchange overpass bridge into portal-type pillars. Portal-type pillars offer several advantages over wall-type pillars. They have better seismic performance due to their increased flexibility and ductility, which allows them to dissipate seismic energy more effectively [4]. Additionally, portal-type pillars have a more open and lightweight structure, reducing the material requirements and construction costs [5].

The redesign of the pillars from wall-type to portal-type aims to enhance the safety, reliability, and cost-effectiveness of the Tanjung Pura interchange overpass bridge. By conducting this research, the author seeks to determine if the portal-type pillar design can compensate for the safety of the existing wall-type pillar structure while considering different dimensions and soil data. The results of this analysis will provide valuable insights into the feasibility and benefits of adopting portal-type pillars in overpass bridge construction.

Furthermore, this research addresses the need for continuous improvement and optimization in bridge design practices. By exploring alternative pillar designs and their performance under different conditions, this study contributes to the advancement of knowledge in bridge engineering and promotes the development of more resilient and sustainable infrastructure.

In summary, the urgency and motivation for conducting this research lie in the potential of portal-type pillars to overcome the limitations of wall-type pillars, enhance the safety and performance of the Tanjung Pura interchange overpass bridge, and contribute to the broader field of bridge engineering. The importance of redesigning the pillars from wall-type to portal-type is emphasized by the need to address seismic vulnerability, optimize material usage, and improve the overall efficiency of the bridge structure.

2 Data and Methods

2.1 Data

The data needed in the plan to redesign the overpass bridge pillars is divided into 2, namely primary data and secondary data:

a. Primary data is data obtained by conducting direct observations/surveys to the field. Field survey to determine the actual condition of the project location and the state of the dimensional form of the finished or completed structure building, as in the review of this proposal, namely the overpass bridge pillar at the Tanjung Pura interchange to find out the initial picture in the redesign planning.
b. Secondary data is data obtained from related agencies which includes soil data, material data, image data.

Location This planning was carried out in North Sumatra Province, precisely on the construction of the Trans Sumatra Toll Road on section 3 (Tanjung Pura - Pangkalan Brandan) and on the Tanjung Pura interchange at STA. 38+000.

The method used in collecting planning data is the literature and documentation method, the method was chosen because the data to be used is sourced from related agencies, namely SOEs and literature or books related to this final project.

The reference guideline data in planning the redesign of the overpass bridge pillars include:

1. SNI 1725 – 2016, concerning Loading Procedures for Bridges [6].
2. SNI 2833 – 2016, concerning Earthquake Resistance Planning Standards for Bridges [7].
3. Road and bridge field guide No.02/M/BM/2021, concerning Practical Guide to Bridge Technical Planning [8].
4. Road and bridge guide: No.02/M/BM/2021 vol.3, concerning Planning of Lower Building Structures and Foundations.
5. RSNI T-12-2004, concerning Planning of Concrete Structures for Bridges.
6. SNI 2052 – 2017, concerning Concrete Reinforcing Steel.

2.2 Methods

The planning steps for the redesign of the Tanjung Pura overpass interchange bridge wall type pillars using portal type pillars are as follows:

1. Collection of existing data used in redesign planning and considered important including:
   a. Existing drawing data that includes the dimensions and initial shape of the bridge structure design ranging from the type of foundation, the type of pillar used, and the shape of the dimensions of the pierhead, and other details if needed in this design planning.
   b. Material data includes the quality of materials used in the overpass bridge pillar structure which is guided by the predetermined SNI and the latest SNI.
   c. Soil data in the form of boring test results data which will be used later to determine the soil carrying capacity and earthquake load.

2. Introduction, at this stage is the collection of literature data from various sources and theories to strengthen in the planning process of this redesign.
3. Planning modeling of overpass bridge pillar redesign using SAP2000 v.20 software and design provisions in accordance with the structural plan and plan material data.
4. The calculation of bridge loading, the loads acting on the bridge are taken into account in such a way as to obtain safe pillar strength. Bridge loads are divided into 2, namely permanent loads and transient loads including.
5. The dead load (own weight) consists of the weight of girder, slab, RC plate, diaphragm.
   a. Additional dead loads consist of heavy barriers, asphalt, and rainwater.
   b. Lane D load or live load consists of two, namely: evenly divided load (BTR) and line load (BGT).
   c. Truck load "TT" load is very influential on the bridge because the type of bridge to be planned is an important bridge.
   d. Brake force load is a load that if it works at an unexpected time and is calculated to reduce the risk that occurs later.
   e. Wind load affects the structure and riders because of the location of the planning in the open land area.
   f. Earthquake load is a load that greatly affects the strength of the bridge structure so that the determination of the earthquake zone is adjusted to the plan data. After all expenses have been calculated, proceed to the stage of changing the load status from nominal to plan by multiplying the load amount and load factor to get the plan load.
6. Unfactored load is not multiplied by the load factor but is continued to the combination in accordance with the loading SNI to determine the amount of force and moment caused by the deep load to calculate the carrying capacity of the soil and proceed later to the calculation stage of the foundation analysis of the bridge pillars.
7. Loading input (plan load) on SAP2000 v.20 software by paying attention to the type of load and unit at the time of load input because the load inputted later is above the pillar head.
8. Analysis of the structure of the output results of the inner forces issued from the running results in the SAP200 v.20 software in the form of (Mu, Vu, and Pu) by first reviewing the ratio issued before manual calculation, after being considered safe namely (0.6-0.8) then continued the calculation of the capacity of the pillar head (pier head), pillar (pier), foundation (pile cap) to be controlled in the next stage.
9. Control the capacity of the pillar consisting of bending, axial and shear capacity from the drawing of the interaction diagram and provided that, if it meets the security requirements of the capacity of the pillar is greater than the actual capacity that occurs then it is considered "safe", otherwise it must repeat from stage 4 and stage 3a. If considered safe, then continue the calculation of repetition used in structures starting from the pillar head (pierhead) and pillar (pier).
10. Foundation planning, the type of foundation used according to the recommendations of the soil test results with the bearing capacity conditions of the soil test results at the soil carrying capacity stage (DDT) to obtain the right and sturdy type of foundation later.
11. Redesign of working drawings (shop drawing), depiction of working drawings guided by existing working drawings to maintain references in planning according to applicable drawing standards.

3 Results and Discussion

3.1 Cross-sectional and material data

The cross-sectional and material data used in the analysis of the redesigned portal-type pier were obtained from the SAP2000 v.20. SAP2000 is a widely used structural analysis and design software that allows users to model, analyze, and design various types of structures, including bridges [9].

To begin the analysis, the geometry of the portal-type pier was defined in SAP2000 based on the selected dimensions. The pier was modeled as a frame element with the following cross-sectional properties:

Cross-sectional data

H pillar height = 8000 mm
Cross sectional height of pillar h = 2500 mm
Cross-sectional width of pillar b = 1500 mm
Cross-sectional area Ag = 3750000 mm2
Moment of inertia:
Transverse direction (x-axis) Ix = 703125000000 mm4
Longitudinal direction (y-axis) Iy = 1367187500000 mm4
X-directional cross-sectional gyration modulus
Transverse direction (x-axis) rx = 433.01 mm
Longitudinal direction (y-axis) ry = 603.81 mm

Material data

Concrete quality f'c = 30 Mpa
Modulus of elasticity of concrete Ec= 25742.96 Mpa
Grade of reinforcing steel fy = 420 Mpa
Steel elasticity modulus Es = 200000 Mpa

SAP2000 automatically calculates the modulus of elasticity for concrete (Ec) and steel (Es) based on the input material properties using the following formulas [10]. These cross-sectional and material properties were then used by SAP2000 to perform the structural analysis of the portal-type pier under the specified loading conditions. The software employs the finite element method to calculate the internal forces, stresses, and deformations in the pier elements [11].

The results of the SAP2000 analysis, including the factored axial loads (P) and bending moments (M22 and M33), were used as input for the subsequent bending capacity analysis using the SP Column v.7 software. The cross-sectional and material data obtained from SAP2000 ensure that the analysis results are consistent with the selected pier dimensions and material properties, providing a reliable basis for the evaluation of the pier's structural performance.

3.2 Analysis of the bending capacity of pillar legs

The cross-sectional capacity of a column can be expressed in the form of an interaction diagram, which represents the relationship between the axial load (Pn) and the bending moment (Mn) capacity of the column. Each point on the interaction diagram corresponds to a specific combination of Pn and Mn for a given cross-section and reinforcement arrangement [12].

To assess the adequacy of the redesigned pier, the factored axial load (Pu) and bending moment (Mu) obtained from the structural analysis are plotted on the interaction diagram. If the (Pu, Mu) point falls inside the interaction curve, the pier cross-section is considered sufficient to resist the applied loads. Conversely, if the point lies outside the curve, the cross-section is deemed inadequate, and modifications to the dimensions or reinforcement may be necessary [13].

Table 1 presents the load combinations considered in the analysis, along with the corresponding factored axial loads (P), and bending moments (M22 and M33) in the transverse and longitudinal directions, respectively.

Table 1. Interaction style table

Load Combination	P	M22	M33
	kN	kN.m	kN.m
Kuat I	19719,74	602,62	20,35
Ekstrem I	12711,02	2323,77	3235,34
Ekstrem I	11395,07	1551,70	3243,08

Table 2 summarizes the results of the bending capacity analysis, including the demand (factored loads), capacity (nominal strength), and the resulting capacity ratio for each load combination. The capacity ratio is calculated by dividing the demand by the capacity and should be less than 1.0 for the pier to be considered safe [14].

Based on the results in Table 2, the following observations can be made:

1. For all load combinations, the capacity ratio is less than 1.0, indicating that the redesigned portal-type pier cross-section with 50D32 main reinforcement is sufficient to resist the applied loads.
2. The maximum capacity ratio of 0.20 occurs under the Extreme I load combination, which represents the most critical loading scenario. Even under this extreme condition, the pier cross-section has a 20% reserve capacity, providing an adequate safety margin.
3. The depth of the neutral axis (NA) and the tensile strain (εt) at the capacity point are also reported in Table 2. These values are used to assess the ductility and performance of the pier cross-section. The relatively small neutral axis depth and the high tensile strain indicate that the cross-section exhibits ductile behavior and can undergo significant deformation before failure [15].

Figure 1 shows the interaction diagram for the redesigned portal-type pier, generated using the SP Column v.7 software. The diagram plots the nominal axial load (Pn) on the vertical axis and the nominal bending moment (Mn) on the horizontal axis. The curve represents the maximum combinations of axial load and bending moment that the pier cross-section can resist.

The interaction diagram and the capacity ratios demonstrate that the redesigned portal-type pier with the selected dimensions and reinforcement arrangement satisfies the strength requirements and provides an adequate margin of safety under the considered load combinations. The ductile behavior of the cross-section ensures that the pier can withstand extreme loading scenarios and dissipate energy effectively during seismic events.

Table 2. Results Load and moment factored with capacity ratio

No.	Demand			Capacity			Parameters at Capacity			Capacity
	P_u	M_{ux}	M_{uy}	ϕP_n	ϕM_{nx}	ϕM_{ny}	NA Depth	ε_t	ϕ	Ratio
	kN	kNm	kNm	kN	kNm	kNm	mm			
1	19719,74	602,62	20,35	19719,74	19661,76	663,93	499	0,00577	0,900	0,03
2	12711,02	2323,77	3235,34	12711,02	11834,80	16477,38	959	0,00442	0,843	0,20
3	11394,07	1551,70	3243,08	11394,07	9541,04	19940,92	1012	0,00477	0,873	0,16

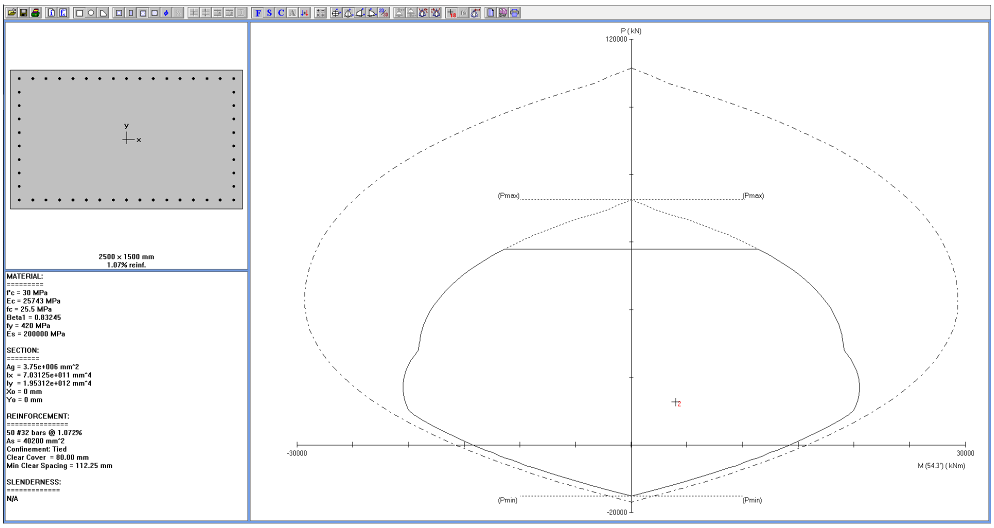

Figure 1. SP Column v.7 pillar interaction diagram

4 Conclusion

The primary objective of this study was to redesign the Tanjung Pura interchange overpass bridge pillars from a wall-type to a portal-type configuration and assess the structural performance and safety of the redesigned pillars. The analysis was carried out using SAP2000 v.20 and SP Column v.7 software, considering various load combinations and design requirements specified in the relevant Indonesian design codes and standards.

Based on the results of the analysis, the following conclusions can be drawn:

1. The redesigned portal-type pillars with dimensions of 1500 mm × 2500 mm and 50D32 main reinforcement were found to be sufficient to resist the applied loads, as demonstrated by the interaction diagram and capacity ratios obtained from the SP Column v.7 analysis. The maximum capacity ratio of 0.20 occurred under the Extreme I load combination, indicating a 20% reserve capacity and an adequate safety margin.
2. The portal-type pillar configuration offers several advantages over the original wall-type design, including improved seismic performance, reduced material usage, and enhanced constructability. The ductile behavior of the redesigned pillars, as evidenced by the small neutral axis depth and high tensile strain at the capacity point, ensures that the pillars can withstand extreme loading scenarios and dissipate energy effectively during seismic events.
3. The redesigned portal-type pillars also incorporate additional leg reinforcement in the plastic hinge regions, with 5D19 - 100 mm in the longitudinal direction and 8D19 - 100 mm in the transverse direction. This reinforcement arrangement enhances the ductility and confinement of the concrete core, improving the pillar's performance under seismic loads.

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