Evaluation of Pile Slab Capacity with Changed Length

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ARTICLE INFO	ABSTRACT
  	Discrepancies between design drawings and field implementation frequently occur in infrastructure projects and may influence the structural performance of foundation systems. One such case was identified in the pile slab structure of the bridge approach at the Serpong–Balaraja Toll Road Section 1A, where a change in pile slab length was observed during construction. This condition raised concerns regarding the ability of the structure to safely carry the applied loads. This study aims to evaluate the structural adequacy of the pile slab after the change in length by examining the capacity of its main structural components. The assessment was conducted through numerical analysis using SAP2000 software, considering dead loads, additional dead loads, live loads, and seismic loads in accordance with Indonesian bridge design standards. The evaluation focused on comparing the bending moments acting on the spun piles with their allowable capacity and verifying whether the reinforcement installed in the capping beam satisfies the required structural demand. The analysis results indicate that the bending moments generated in the spun piles remain below the permissible cracking moment, while the reinforcement provided in the capping beam is sufficient to resist the internal forces obtained from the analysis. These findings demonstrate that the pile slab structure maintains adequate structural performance despite the geometric modification. It can therefore be concluded that the pile slab system remains capable of supporting the working loads without requiring additional strengthening. The results highlight the importance of structural re-evaluation when construction deviations occur, ensuring safety while maintaining efficiency in bridge foundation design.

Keywords: pile slab, structural capacity, SAP2000 |

1. Introduction

The rapid development of infrastructure in Indonesia is closely related to population growth and continuous advancements in construction technology. As a result, the demand for reliable structural planning has increased, particularly for large-scale infrastructure projects such as bridges and toll roads. Proper planning is essential to ensure that structures are capable of safely transferring loads from the superstructure to the supporting ground throughout their service life [1][2].

One of the major infrastructures currently under development is the Serpong–Balaraja Toll Road Section 1A, which includes the Cisadane Bridge as one of its longest-span bridges. The bridge is designed with a prestressed concrete (PCI) girder superstructure spanning 50.8 meters. At the bridge approach section, specifically at Sta 2+500–2+564, a pile slab structure is used to support the roadway system. This type of structure functions as a foundation system composed of a group of piles connected by a pile cap or capping

beam, enabling the transfer of loads from the superstructure to deeper soil layers with adequate bearing capacity [3][4].

In general, foundations play a critical role in ensuring structural stability by distributing loads safely to the ground [5]. For bridge structures subjected to significant vertical and lateral loads, spun pile foundations are commonly adopted due to their high strength and ability to reach deeper, more competent soil layers [6]. The pile slab system applied in this project consists of spun piles, capping beams, and bridge floor slabs, where the capping beam acts as a structural element that binds the piles together and distributes loads uniformly from the upper structure [7]. The configuration of the pile slab structure applied in the Serpong–Balaraja Toll Road project is illustrated in Figure 1.

Figure 1. Pile slab structure on serpong-balaraja toll road project

During field implementation, discrepancies were identified between the shop drawings and the actual constructed condition, particularly related to changes in the length of the pile slab structure. The designed pile slab includes piles with a diameter of 60 cm, a free-standing height of 6 meters above ground level, and pile groups consisting of 11–12 piles per segment. However, measurements conducted on site revealed that the installed pile slab length differed from the original design. Such changes may influence the internal forces acting on the structure and potentially affect its structural performance.

Considering these conditions, it is necessary to evaluate the structural capacity of the pile slab after the change in length. This evaluation is intended to determine whether the existing pile slab configuration remains capable of resisting the applied loads safely or whether structural strengthening is required. Therefore, this study focuses on assessing the capacity of the pile slab structure under modified geometric conditions by analyzing the strength of the capping beam (Figure 2) reinforcement and the bending capacity of the spun piles, in accordance with applicable design standards.
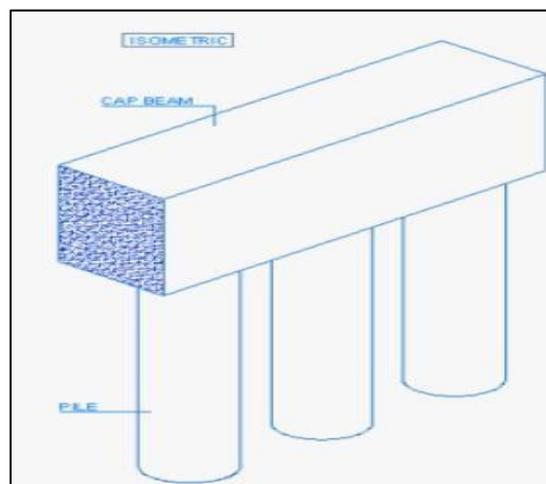
Figure 2. Modeling of capping beam

2. Method

This study applies a quantitative-analytical approach to evaluate the structural capacity of a pile slab system that experienced a change in length during field implementation. The research procedure was designed to ensure that the structural performance of the modified pile slab could be assessed reliably under applicable loading conditions and design standards. An overview of the research workflow is presented in Figure 3.
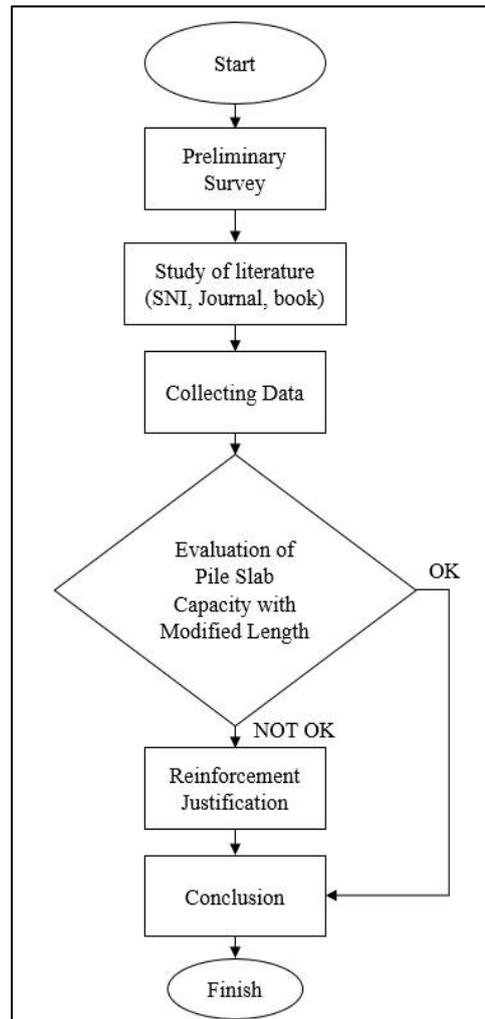

Figure 3. Flow chart

The first stage of the study involved a preliminary field survey conducted at the bridge approach structure of the Serpong–Balaraja Toll Road Section 1A, located at Sta 2+500–2+564 near the Cisadane Bridge. This survey aimed to identify the existing geometric conditions of the pile slab structure and to verify discrepancies between the shop drawings and the actual construction. Primary data were obtained directly from field measurements, including pile spacing, pile dimensions, free-standing height, and slab geometry.

Secondary data were collected from the project contractor, PT Multi Phi Beta, consisting of Detail Engineering Design (DED) documents, material specifications, and soil investigation reports. These data served as the basis for defining material properties, soil parameters, and initial design assumptions used in the structural analysis.

The technical characteristics of the pile slab structure analyzed in this study include a foundation diameter of 0.6 m (Type A1), a pile length of 34 m with an embedded depth of 28 m, and a free-standing height of 6 m above ground level. The floor slab thickness is 0.35 m, with a segment length of 7.5 m and pile spacing of 3.7 m. The capping beam has a width of 1.3 m and a height of 0.7 m. The cross-sectional configuration of the pile slab and the details of the spun pile are illustrated in Figure 4 and Figure 5, respectively.
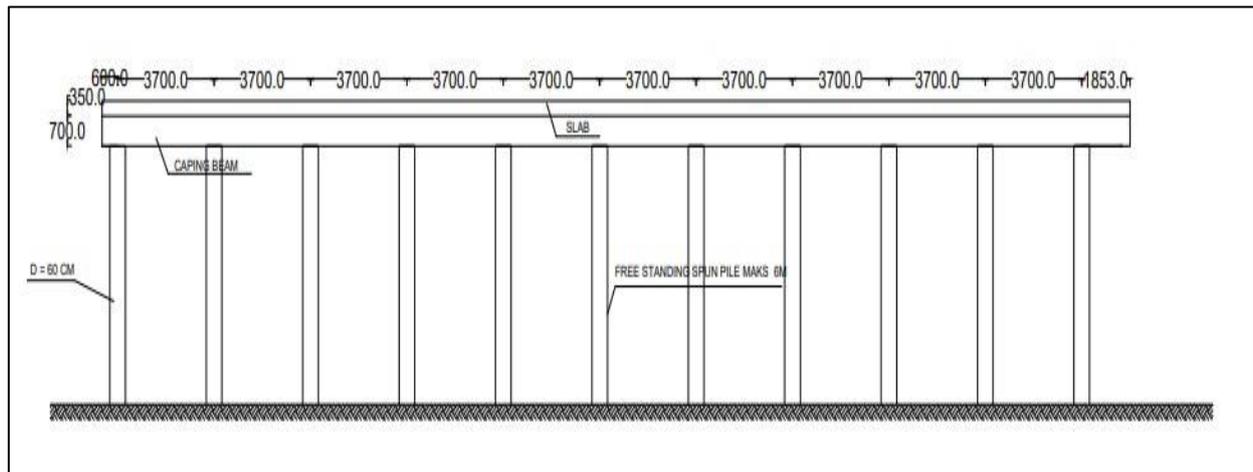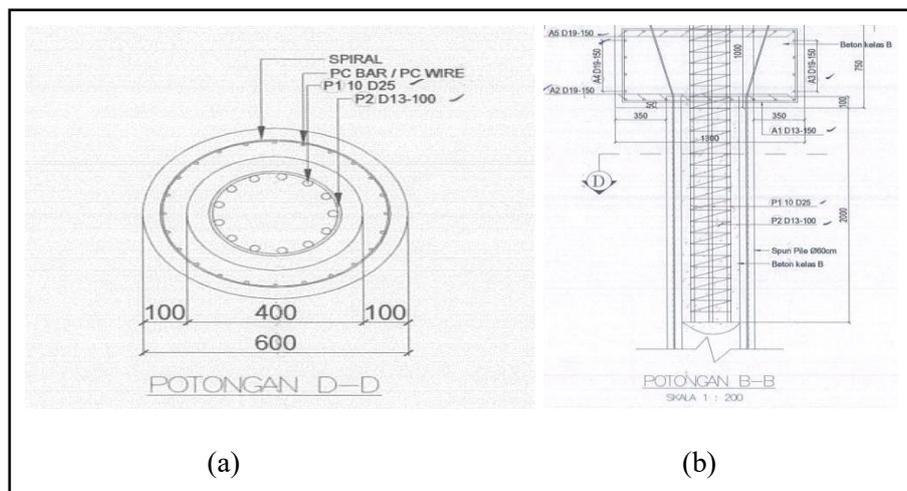
Figure 4. Cross section pile slab

Figure 5. Detail spun pile

Structural loading was determined in accordance with Indonesian design standards. Permanent loads, additional dead loads, live loads, and earthquake loads were calculated based on SNI 1725:2016 concerning bridge loading and SNI 2833:2008 concerning seismic design for bridges. Load combinations were defined to represent the most critical conditions acting on the pile slab structure. To represent soil–structure interaction, spring constants were introduced into the pile foundation model. The soil spring constants were defined in both vertical and horizontal directions to simulate ground resistance against pile deformation. The spring stiffness values were determined based on soil parameters obtained from field investigations and established correlations, ensuring that the lateral and axial behavior of the piles could be realistically captured in the numerical model.

The pile slab structure was then modeled using SAP2000 software by incorporating geometric dimensions, material properties, loading conditions, and soil spring constants derived from previous stages. The numerical model was used to analyze internal forces, particularly bending moments acting on the spun piles and the capping beam. Structural capacity evaluation was carried out by checking two main components: the reinforcement capacity of the capping beam and the bending capacity of the spun piles. The capping beam reinforcement was assessed by comparing the required reinforcement obtained from analysis with the reinforcement installed in the field. Meanwhile, the spun pile capacity was evaluated by comparing the resulting bending moments from the analysis with the allowable moment capacity specified for the pile type.

If the analysis results indicated that the internal forces exceeded the allowable capacities, structural strengthening would be recommended. Otherwise, the pile slab structure would be considered adequate to support the applied loads. The conclusions were drawn based on the results of these capacity checks, providing an assessment of the structural safety of the pile slab after the change in length.

3. Results and Discussion

The structural performance of the pile slab system was evaluated by considering all relevant load components acting on bridge structures in accordance with SNI 1725:2016 [8][9]. The applied loads include dead loads, additional dead loads, live loads, and earthquake loads, which were analyzed to assess the adequacy of the pile slab after experiencing a change in length during construction.

Dead loads originating from the self-weight of structural components were automatically generated by SAP2000 based on the defined geometry and material properties. In addition to self-weight, super dead loads were calculated explicitly, particularly those arising from asphalt layers and parapet structures. The asphalt layer was assumed to have a thickness of 0.05 m and a unit weight of 22 kN/m³. The resulting super dead loads vary according to the effective floor width of each segment, as summarized in Table 1. The results show that segments with greater slab widths generate higher super dead loads, which directly affect the internal forces acting on the pile slab structure.

Table 1. Super dead load asphalt

Segment	Floor Width (m)	SDL Asphalt (kN/m)
A2	1,14	4,829
	3,75	4,125
	3,71	4,081
	0,6	4,191
P7	1,48	5,203
	3,75	4,125
	3,73	4,081
	0,6	4,191
P6	1,84	5,599
	3,75	4,125
	3,71	4,081
	0,6	4,191
P5	2,23	1,903
	3,75	4,125
	3,71	4,081
	0,63	4,224
P4	2,63	2,343
	3,75	4,125
	3,71	4,081
	0,68	4,279
P3	3,07	2,827
	3,75	4,125
	3,71	4,081
	0,77	4,378
P2	3,52	3,322
	3,75	4,125
	3,71	4,081
	0,89	4,51
P1	4	3,85
	3,75	4,125
	3,71	4,081

Segment	Floor Width (m)	SDL Asphalt (kN/m)
	1,06	4,697
A1	4,5	4,4
	3,75	4,125
	3,71	4,081
	1,28	4,939

Parapet loads were calculated based on a cross-sectional area of 0.5438 m² and a concrete unit weight of 25 kN/m³, resulting in a uniformly distributed load of 13.595 kN/m. The parapet geometry applied in the analysis is illustrated in Figure 6, and this load was applied along the length of the pile slab to represent the actual field condition.
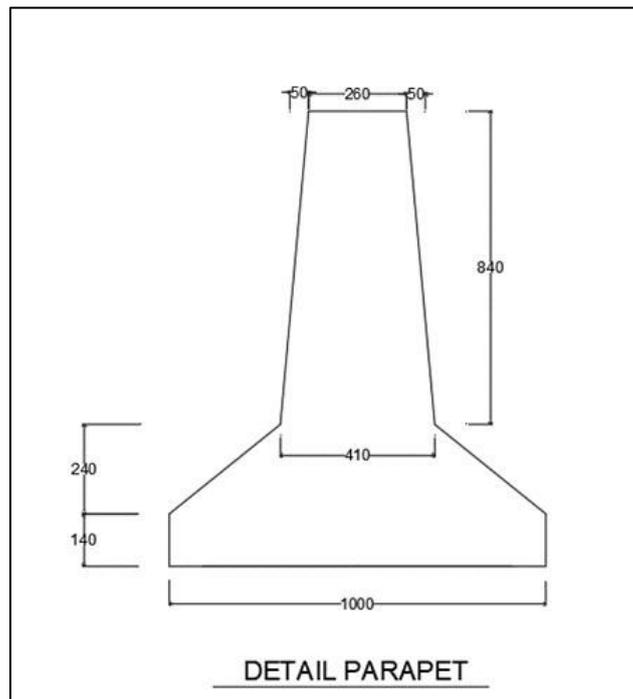

Figure 6. Detail parapet on struktur pile slab

Live loads were determined in accordance with SNI 1725:2016 [8][9], which specifies BGT and BTR load components. The BGT load was applied as a centralized line load with a nominal value of 49 kN/m multiplied by a dynamic load factor, resulting in an effective load of 68.6 kN/m. Meanwhile, the BTR live load was calculated based on variations in slab width, with the resulting load intensities presented in Table 2. The data indicate that wider roadway slabs contribute larger live load demands, thereby increasing the bending moments and shear forces transmitted to the pile slab system.

Table 2. Calculation of live load

Live Load (BTR)	
Floor Width (m)	QLL (kN/m)
1,14	29.6325
1,48	31.9275
1,84	34.3575
2,23	11.6775
2,63	14.3775
3,07	17.3475

Live Load (BTR)	
Floor Width (m)	**QLL (kN/m)**
3,52	20.385
4	23.625
4,5	27
0,6	25.7175
0,63	25.92
0,68	26.2575
0,77	26.865
0,89	27.675
1,06	28.8225
1,23	29.97
3,71	25.0425
3,75	25.3125

Earthquake loading was evaluated using the provisions of SNI 2833:2008 [10][11][12]. The seismic analysis considered parameters such as structural weight, elastic response coefficient, and modification factor. The total structural weight was obtained from SAP2000, including a portion of the live load, where a live load participation factor of 0.5 was applied in accordance with toll road bridge requirements. The elastic response coefficient was selected based on the seismic zoning of Serpong, South Tangerang, and the fundamental period of the structure. Seismic loads were applied at the center of mass, with a combination of 100% transverse and 30% longitudinal action to represent critical loading conditions.

To account for soil–structure interaction, soil spring constants were incorporated into the numerical model of the pile foundation. The soil surrounding the spun piles was modeled using vertical and horizontal springs derived from corrected N-SPT values, following the approach proposed by Bowles [13] and supported by previous studies on pile foundation behavior [7]. The vertical and horizontal spring constants were calculated using established correlations between soil bearing capacity and N-SPT values, enabling a realistic representation of pile stiffness within the SAP2000 model. The resulting three-dimensional pile slab model is shown in Figure 7.
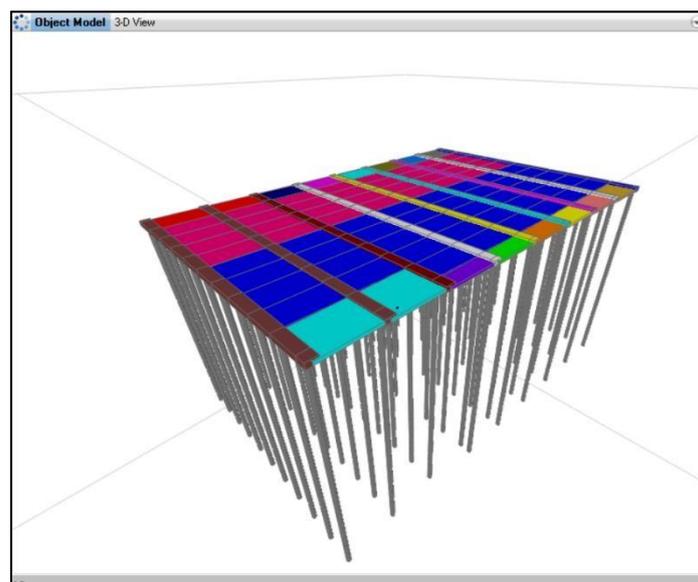

Figure 7. Modeling of struktur pile slab

The capacity evaluation focused on assessing the bending capacity of the spun piles and the reinforcement capacity of the capping beam. The spun pile capacity was evaluated based on the allowable cracking moment specified in JIS A 5335:1987, with analytical bending moments obtained from SAP2000 compared against the

permissible limit. The results, presented in Figure 8 and Table 3, indicate that the maximum bending moments under both seismic and non-seismic conditions remain below the allowable moment of 17 ton·m. This confirms that the spun piles maintain sufficient structural capacity despite the change in pile slab length, which is consistent with previous findings on pile performance under lateral and combined loading [5][14].
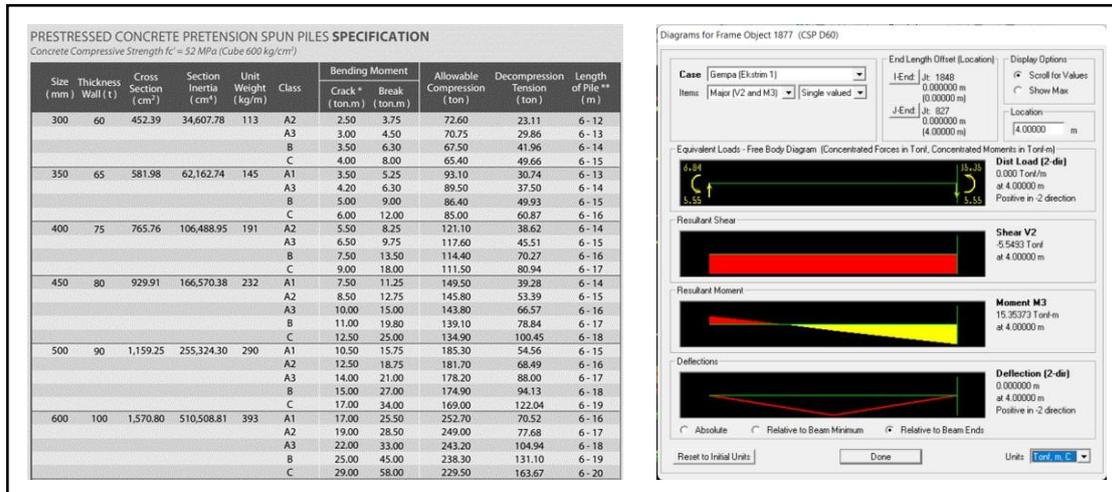

Figure 8. Specification of spun pile type A1 and moment of analysis result in SAP2000

Table 3. Capacity of spun pile

Capacity of Spun Pile				
	Moment on spun pile		clearance moment on spun pile	Description
Segment	due to earthquake load	Without earthquake load		
Center of structure	15,35 ton.m	0,18 ton.m	17 ton.m	Adequate
Center of P7	15,44 ton.m	0,2 ton .m		
Edge of P7	10,99 ton.m	1,6 ton .m		

The reinforcement capacity of the capping beam was evaluated in accordance with SNI T-12-2004 [15][16] by comparing the required reinforcement obtained from structural analysis with the reinforcement installed in the field. The comparison, summarized in Table 4, shows that the installed reinforcement configuration (D19– 150 mm) satisfies the required reinforcement demand under both earthquake and non-earthquake load combinations. These results demonstrate that the capping beam remains structurally adequate without the need for additional strengthening.

Table 4. Comparison of the analysis results with the installed reinforcement

Load	Result Analysis	Actual Condition	Description
due to earthquake	D19-153,16 mm	D19-150 mm	adequate
Without earthquake	D19-153,38 mm	D19-150 mm	adequate

Overall, the analysis results indicate that the pile slab structure remains capable of resisting the applied loads even after the observed change in length. The internal forces generated by dead loads, live loads, and seismic loads do not exceed the capacity of either the spun piles or the capping beam reinforcement. This outcome suggests that the original structural design provided sufficient reserve capacity to accommodate moderate geometric changes during construction. From an engineering standpoint, these findings emphasize the

importance of re-evaluating structural capacity when deviations occur between design drawings and field conditions, as such evaluations help ensure structural safety and prevent unnecessary strengthening measures [1][3][6].

4. Conclusion

This study evaluated the structural capacity of a pile slab system that experienced a change in length during construction at the Serpong–Balaraja Toll Road project. The assessment was carried out by analyzing the combined effects of dead loads, live loads, and seismic loads in accordance with applicable Indonesian design standards, supported by numerical modeling using SAP2000.

The analysis results indicate that the internal forces generated within the pile slab structure remain within allowable limits. The bending moments acting on the spun piles are lower than the permissible cracking moment specified in JIS A 5335:1987, confirming that the piles are able to safely resist the applied loads. In addition, the reinforcement installed in the capping beam satisfies the reinforcement demand obtained from structural analysis, both under seismic and non-seismic load combinations.

Based on these findings, it can be concluded that the pile slab structure remains structurally adequate despite the observed change in length, and no additional strengthening measures are required. The results emphasize the importance of conducting structural re-evaluation when discrepancies arise between design drawings and field implementation, as such evaluations help ensure structural safety while avoiding unnecessary modifications.

5. Acknowledgements

6. Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper. The research was conducted independently, and the results presented in this study were not influenced by any commercial or financial relationships.

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