RESEARCH ON THE PERFORMANCE OF CURVED INTEGRAL ABUTMENT BRIDGES IN VIETNAMESE CONDITION

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Abstract

This article presents results of studying the performance of span structure in the curved integral abutment bridges; the behavior of the ground behind integral abutment bridge when changing the form of approach/transition slap according to the standard TCVN 11823-2017. Based on the studied results, recommendations were made on the applicability of the integral bridges in Vietnamese condition.

Keywords: *Integral bridge; Midas Civil 2011; Plaxis 8.2; finite element method; structure; soil-structure interaction.*

1. Introduction

Integral bridges with outstanding advantages are increasingly being applied and built around the world. According to statistics in the United States, the design and construction of new small and medium-sized bridges, the universal bridge is the first choice for design in 38/50 surveyed states. As of 2008, there have been over 13,000 monolithic and semi-integral bridges built throughout the United States [1].

Many research documents have shown that the integral bridges have many outstanding advantages such as: they have completely eliminated expansion joints and bridge bearings, which make the vehicles circulate smoothly on the bridge. Meanwhile, operation costs and efforts have been reduced a lot due to no need to carry out maintenance and repair of expansion joints and bridge bearings. The approaching slab to the bridge is built monolithically with the abutment body wall to ensure a smooth transition between the road and the bridge during the operation, there is no gap behind the abutment crest wall, therefore the bridge leading plate should be eliminated. Prevent surface water seeping into the roadbed behind the abutment, one of the main causes of subsidence and cracking of the roadbed. Bridge structure is slender and compact, ensuring aesthetics. Construction cost of an intergral bridge is significantly reduced in compare to that of traditional bridges with the same size; moreover, construction time is shortened and construction technology is simplified a lot. The overall height of the bridge can be increased, ensures better dynamic load capacity, and is suitable for application in earthquake areas,…[2, 3].

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Integral bridges with many of the above advantages are increasingly and widely being applied in countries around the world. However, in Vietnam, integral bridges are still under research and testing phase. This article studies the behaviour of the curved integral abutment bridges, in order to evaluate the applicability for this type of bridge in Vietnamese conditions.

2. Surveying the performance of the curved integral bridges in Vietnam's conditions

The authors survey the performance of the curved integral bridges according to geological and climatic conditions and Vietnamese standards using Midas Civil 2011 v2.1 software. The spatial modeling problem, the interaction between the abutment and the pile system with the soil in the model on Midas Civil 2011 v2.1 is replaced by springs interacting in all directions in space.

- **Geometric parameters of the problem:**

Curved integral bridges with variable number of spans, bridge width B = 12 m, prestressed reinforced concrete hollow slab girder; steel piles usually use O-shape (O508x12.7) according to ASTM Standard for survey. Concrete strength of the surveyed problem: 1) 35 MPa for concrete beams, bridge decks and transition slabs; 2) 24 MPa for abutment and piers. The remaining parameters are shown in Figures 1 and 2.

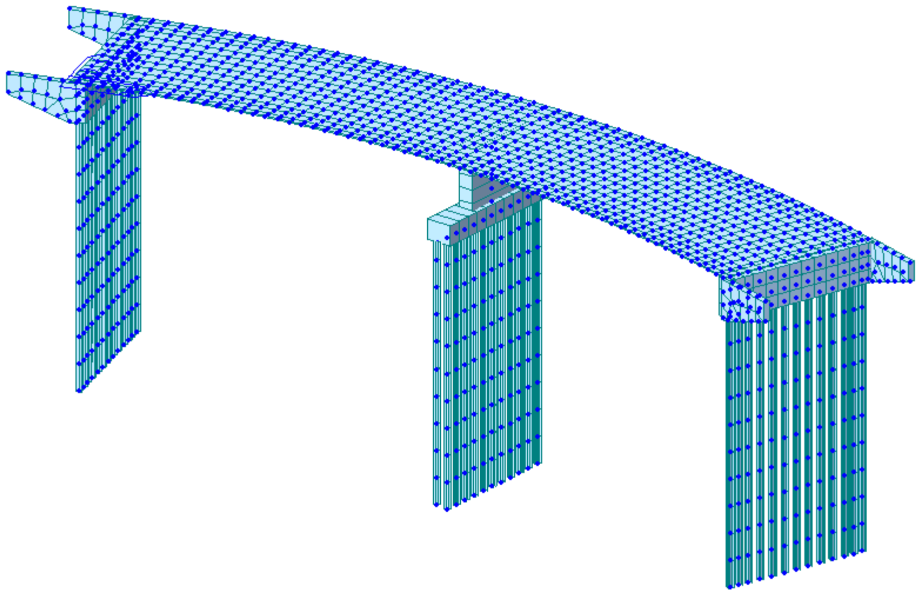


Figure 1. Spatial model of the surveyed problem in Midas Civil.

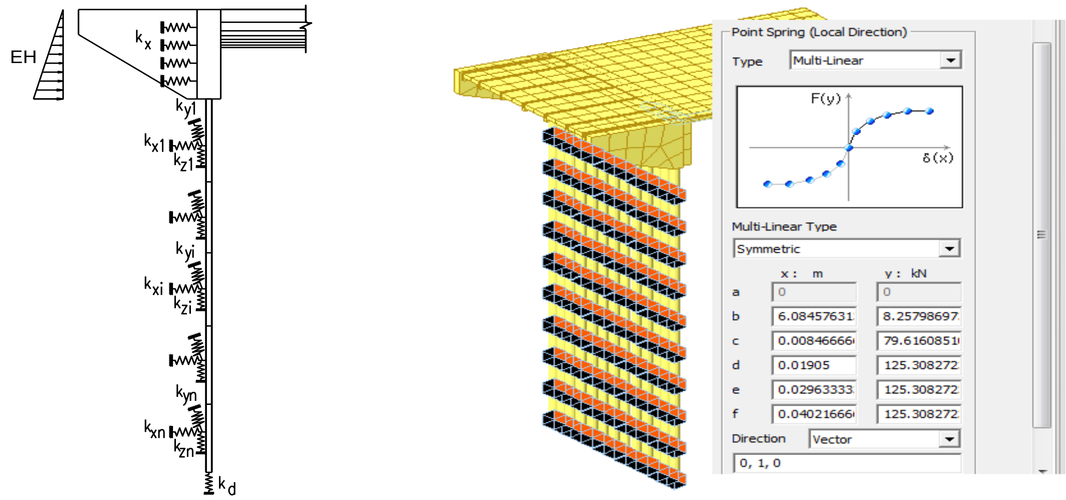


Figure 2. Soil interaction diagram and bridge structure model in Midas Civil.

- **Geological data and material characteristics of the problem:**

The geology behind the abutment and below abutment foundation is heterogeneous including 4 layers. The specific parameters are shown in Table 1.

Table 1. Geological data and material characteristics

Parameter	Symbol	Material Type						Unit
		Grade 1	Grade 2	Grade 3	Grade 4	Abutments	Pillars	
Material model	Model	M-C	M-C	M-C	M-C	Elastic	Elastic	-
Type of analysis	Type	Drained	Drained	Drained	Drained	Non-porous	Non-porous	-
Soil layer thickness	-	4	4	17	>10	-	-	m
Unsaturated unit weight	γunsat	16.3	15.8	17.6	19.5	24	78.5	kN/m^3
Saturated unit weight	γsat	19.5	18.7	20.9	21.4	-	-	kN/m^3
Young's modulus	E	8400	16100	31500	38500	29.2E6	200E6	kN/m^2
Poisson's ratio	ν	0.3	0.3	0.3	0.3	0.2	0.3	-
Cohesion	c	10.8	0.2	23.0	24.5	-	-	kN/m^2
Internal Friction angle	φ	15.47	31.09	21.17	21	-	-	Degrees
Dilatancy angle	ψ	0	1.09	0	0	-	-	Degrees
Strength reduction factor for contact of soil and structures	Rinter	0.68	0.75	0.85	0.85	-	-	-

- **Load:**

Investigate the operation of the curved integral bridges under the effect of a combination of loads including regular loads, live loads, seasonal positive and negative temperature changes: self-weight of DC structural members, self-weight of deck cover DW, horizontal soil pressure EH, live load behind abutment LS, braking force BR, effect of seasonal temperature change TU and live load HL-93 [4, 7].

Load combinations considered in the problem:

$$CH1 = 1.25DC+1.5DW+1.5EH +1.75(HL93+IM+BR)+1.75LS+1.2TU(+)$$

$$CH2 = 1.25DC+1.5DW+1.5EH +1.75(HL93+IM+BR)+1.75LS+1.2TU(-)$$

- **Surveyed results:**

Investigate the working of the whole curved integral bridges when changing the number of spans from 1 to 5 spans, the span length changes 20 m and 30 m, radius of curvature is fixed at R = 700 m, structures are subjected to adverse load combination CH2.

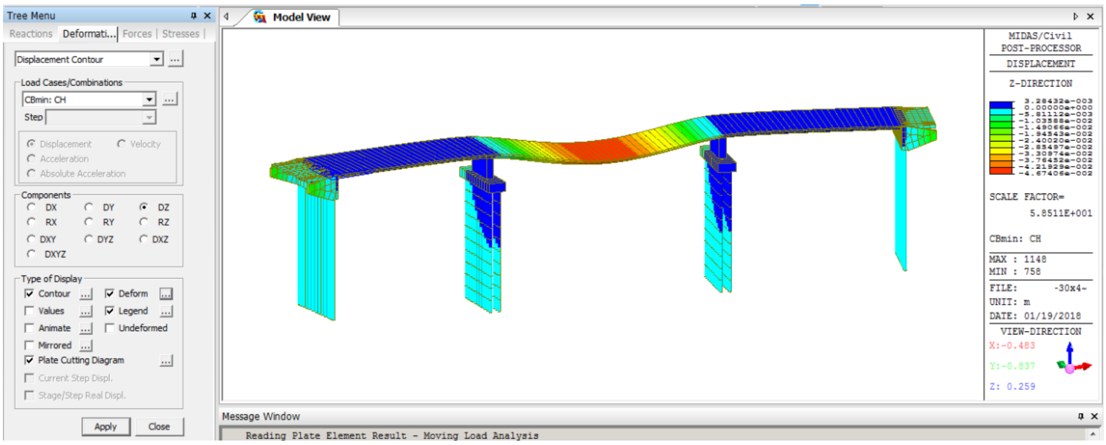


Figure 3. The maximum displacement at the middle span with the 3-span full curved integral bridges, the radius of curvature R = 700 m with the load combination CH2.

The results of the maximum displacement in the D_{xy} direction when examining the change in the number of spans and the span length with the whole curved integral bridges are shown in Table 2.

Table 2. Maximum displacement D_{xy} at the top of the integral curved abutment

Span length *l*, (m)	The values of the largest abutment displacements D_{xy} (mm) for bridge diagram with the number of spans				
	1	2	3	4	5
20	9.1	7.0	9.2	13.8	18.1
30	15.7	12.3	16.2	21.3	26.8

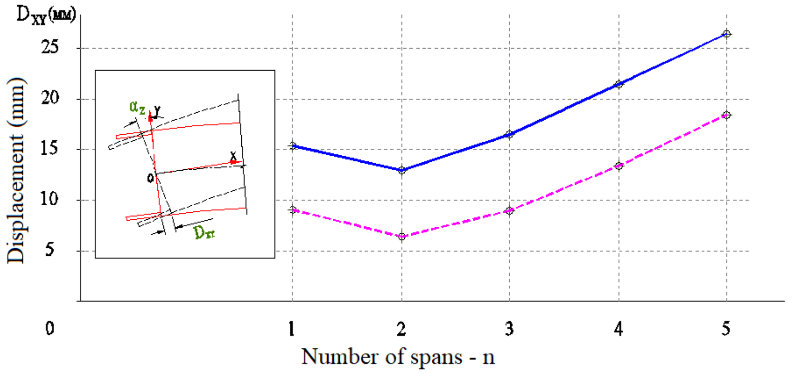


Figure 4. Relationship between the maximum displacement of the abutment when changing the number of spans and span length with the curved integral bridge.

The maximum rotation angle at the top of the abutment α_z when examining the change in the number of spans and span length with the whole curved integral bridge is shown in Table 3.

Table 3. Maximum rotational displacement α_z at the top of the integral curved abutment

Span length *l*, (m)	The values of the angles of rotation α_z (10^{-4}rad.) at the top of the abutment for bridge diagram with the number of spans				
	1	2	3	4	5
20	2.4	1.8	2.5	3.1	3.5
30	3.3	2.8	3.6	3.9	4.1

The surveyed results have shown that, with the 2-span curved integral bridge, the displacement D_{xy} is the smallest. When changing the span length from 20 to 30 m, the maximum displacement value of the abutment crest also increases from 30 to 40% depending on the number of spans of the bridge. The absolute value of D_{xy} does not exceed 2.5 cm, which is within the allowable limit according to US standards [6].

Similar to the translational displacement D_{xy}, the angle of rotation of the abutment with the curved integral bridge also increases from 15-30% when the span length is increased from 20 to 30 m.

From the research results, it can be seen that, with 2-span curved integral bridge, the translational displacements and rotation angle at the top of abutment are more beneficial than with 1-span arched bridges. When the number of spans is more than 3, with the curved integral bridge, there should be more requirements on the abutment structure as well as measures to reduce the maximum rotational displacement when the radius of curvature of the bridge is smaller.

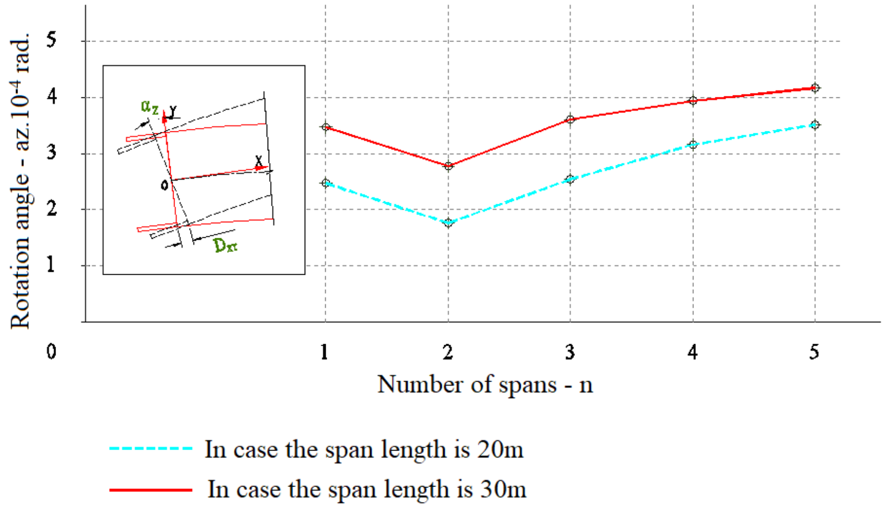


Figure 5. Relationship between the maximum rotation angle of the abutment when changing the number of spans and span length with the whole integral curved abutment.

3. Investigate the performance of the curved integral bridge with consideration of soil - structure interaction using the Plaxis 8.2 software

Surveying the working of the 2-span, curved integral bridge, span length of 30 m, radius of curvature of the bridge R = 700 m. Parameters of soil foundation, size of abutment and piles are the same as in item 2 above.

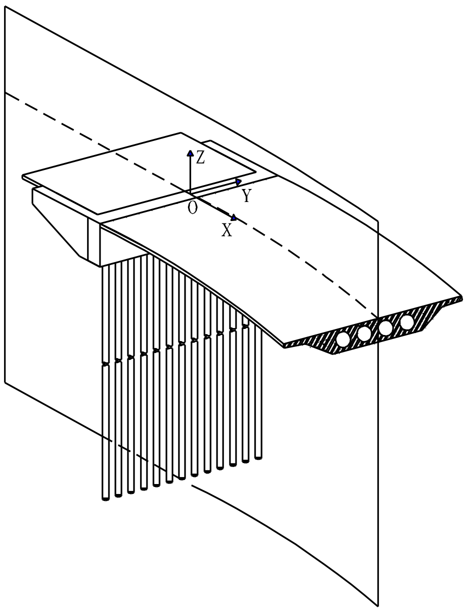


Figure 6. Problem survey plane in Plaxis.

• **Input parameters:**

The structure of the abutment is investigated by the authors as recommended by the US as shown in Figure 7 [5, 6]; geological data as shown in Table 1; Input parameters of structural elements are shown in Table 4.

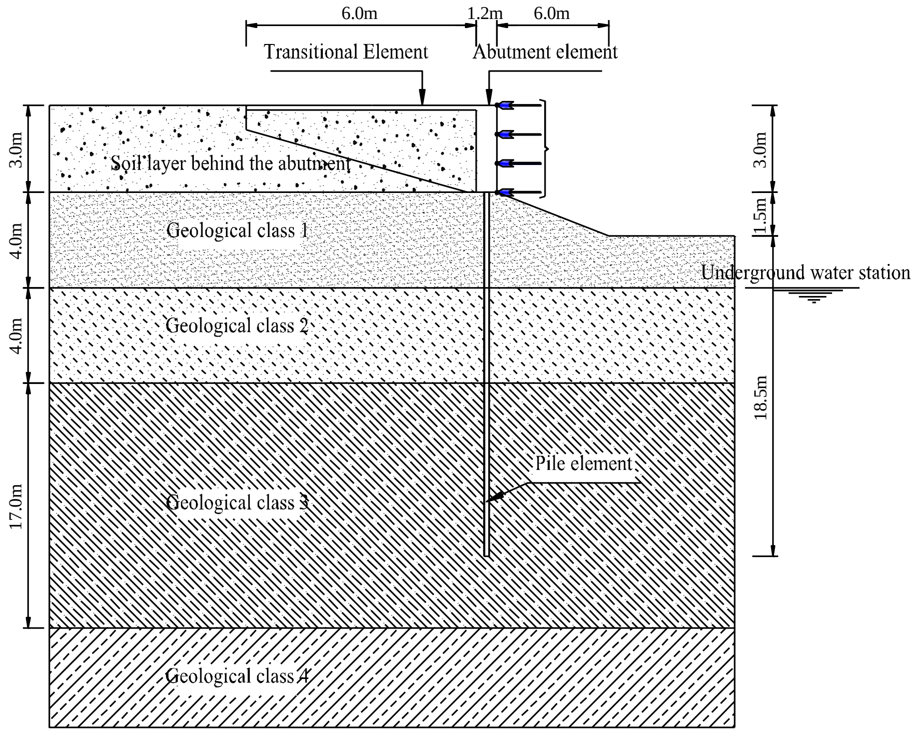


Figure 7. The diagram of the problem model in Plaxis 8.2 and the form of abutment using in the survey.

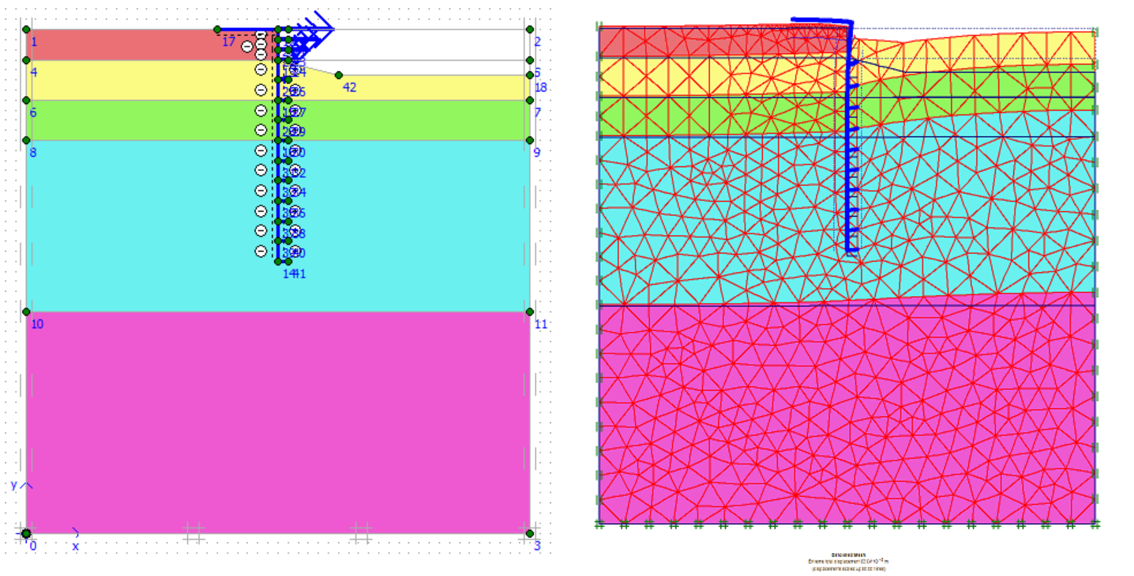
Table 4. Input parameters of structural elements

Input parameter	Symbol	Structural element			Unit
		Transitional element	Abutment element	Pile element	
Material model	Model	Elastic	Elastic	Elastic	-
Axial stiffness	EA	7.30E+6	3.50E+7	3.99E+6	kN/m
Bending stiffness	EI	3.80E+4	4.20E+6	1.23E+5	$kN/m^2/m$
Replacement volume	w	2.05	9.84	17.60	kN/m/m
Poisson's coefficient	ν	0.2	0.2	0.3	-

Forced displacement investigated in the problem is taken for 2 cases of CH1 and CH2 load combinations. The model in Midas to get the forced displacement value when put into Plaxis needs to remove the earth pressure behind the abutment EH:

Table 5. Forced displacement values included in the model in Plaxis

Forced displacement point	U_{x1} (mm)	U_{x2} (mm)	U_{x3} (mm)	U_{x4} (mm)	U_{x5} (mm)	U_{x6} (mm)	U_{x7} (mm)
Load combination CH1	-6.225	-6.417	-6.667	-7.076	-3.458	0.048	0.164
Load combination CH2	9.239	6.917	5.276	3.742	1.467	0.437	0.035
Transposition point position	Peak abutment (+3m)	Body abutment (+2m)	Body abutment (+1m)	The top of the pile (0m)	-2m	-4m	-6m



a) Problem input model *b) The result of the general displacement of the problem*

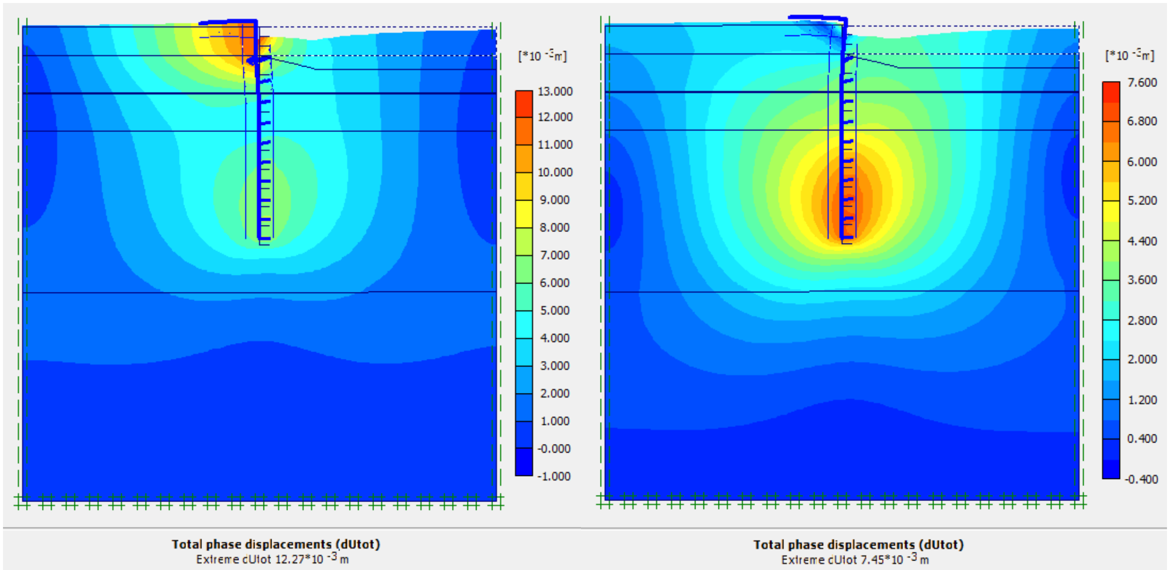
Figure 8. Problem model in Plaxis 8.2 (with CH2 combination).

- **Surveyed results:**

Through investigation of the problem, the overall deformation and deformation at the transition slab position with the combination of loads CH1 and CH2 are obtained as shown in Figure 8, Figure 9. The maximum displacement of the transition slab is obtained as shown in Table 6.

Table 6. Maximum displacement value at abutment crest and transition slab with load combinations

Load combination	Peak abutment		In the middle of the transition slab		Extreme version	
	U_x (mm)	U_y (mm)	U_x (mm)	U_y (mm)	U_x (mm)	U_y (mm)
Load combination CH1	-6.225	12.761	-6.224	11.391	-6.223	8.459
Load combination CH2	9.236	13.091	9.238	16.285	9.238	17.705



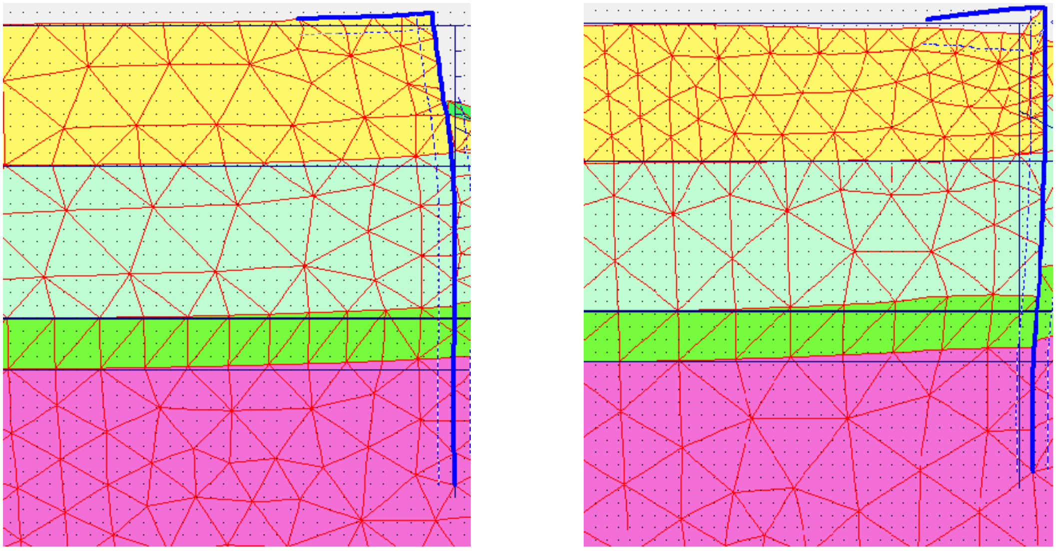
a) With load combination CH1 *b) With load combination CH2*

Figure 9. Total phase displacement calculated with different load combinations.

Under seasonal temperature changes, as well as the effects of static loads and frequent live loads, the ground behind the curved integral bridge is often in two states of tension and compression.

Figure 10 shows the deformation of the abutment and the ground behind the curved integral abutment under the effect of load combination CH1 and CH2.

The results of the survey show that, under the effect of the CH1 load combination when the temperature change is positive, the ground behind the abutment is compressed, the largest displacement of the ground is 3 cm; In contrast to the CH2 load combination when the seasonal temperature change is negative, the ground is stretched and the maximum displacement in the Dz direction is 2.8 cm (Figure 11).



a) *b)*

Figure 10. Deformation of abutment and ground behind curved integral abutment under the effect of load combination: a) CH1, b) CH2.

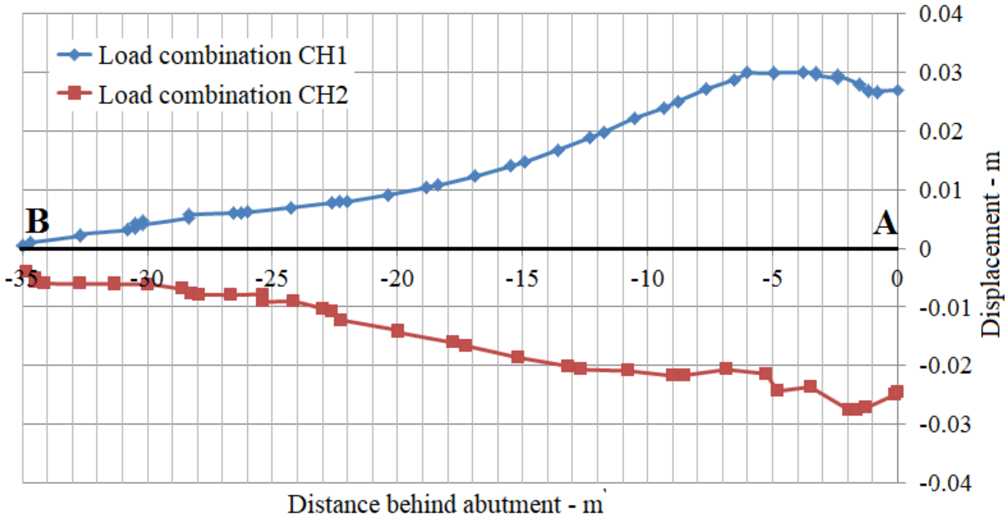
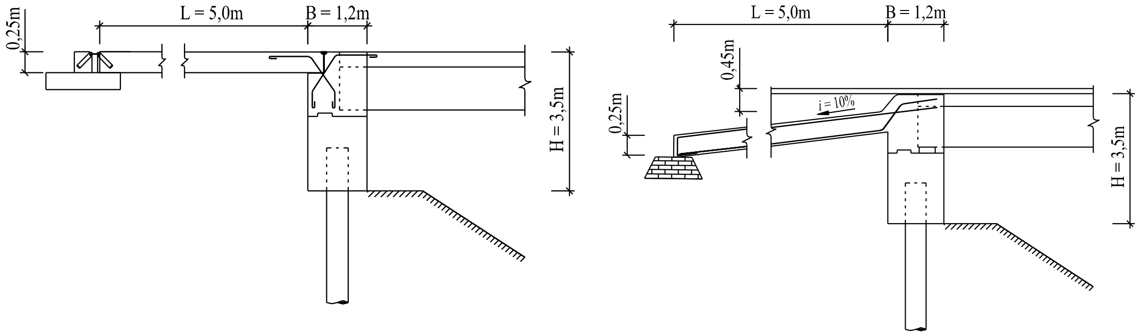


Figure 11. Displacement D_z of the ground behind the curved integral abutment.

The compaction and expansion of the ground will repeat a long-term process, forming a subsidence area right at the position of the abutment crest adjacent to the ground behind the abutment of the curved integral abutment. The chart also shows that the soil behind the abutment is affected to a distance of about 35 m behind the abutment wall. The study and application of the appropriate type of transition slab behind the bridge abutment is meaningful in limiting those negative impacts on the bridge's operation.

- **The influence of the form of the transition slab on the behavior of the ground behind the curved integral abutment**

The basic dimensions of the two types of survey abutments are shown in Figure 12.



a) *b)*

Figure 12. Dimensions of survey abutment: a) Type 1; b) Type 2.

Research and evaluate the performance of two types of transient slabs as input to the problem, in which the deformation of the ground-structure system in the case of type 2 transient slabs when under the influence of a construction CH2 load combination. Analysis model built on the Plaxis software is shown in Figure 13.

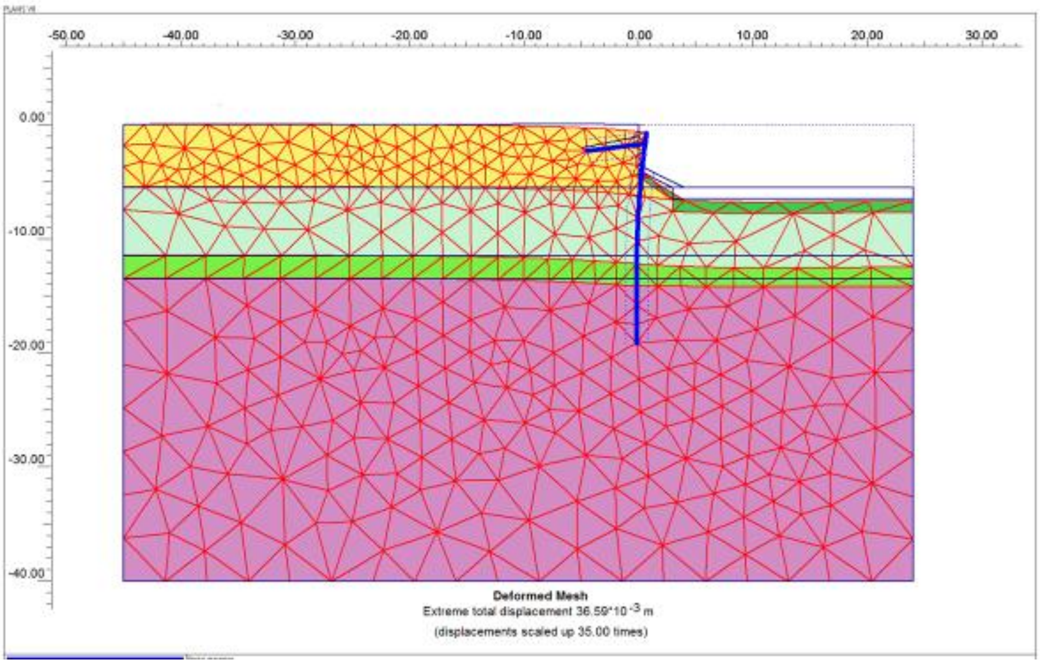


Figure 13. Model of ground deformation behind abutment with type 2 abutment under the influence of CH2.

Comparing the deformation of the ground behind the abutment with the two types of abutment studied under the influence of the load combination CH1 and CH2 gives the results as shown in Figure 14.

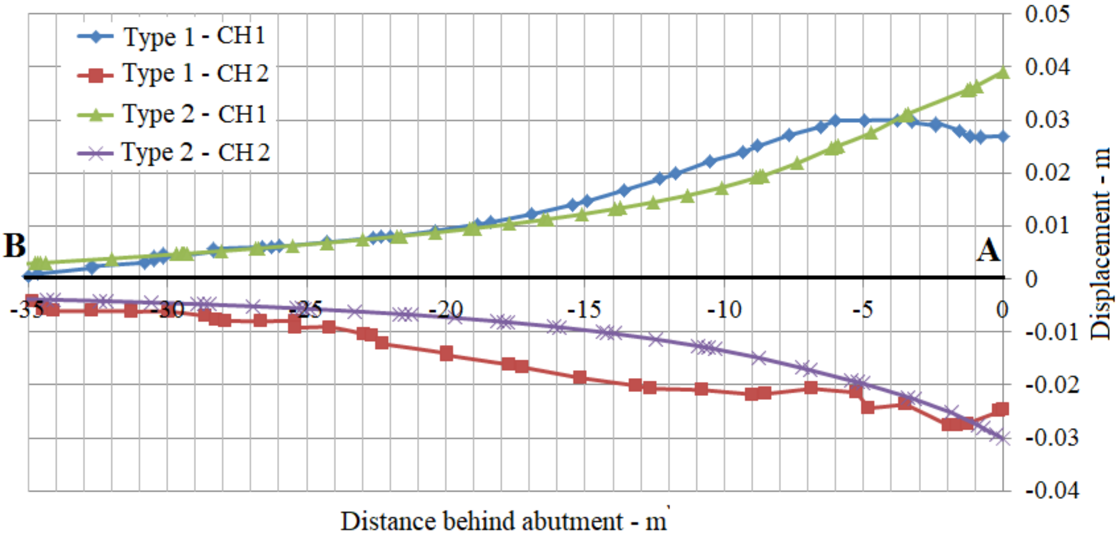


Figure 14. Displacement of the ground behind the abutment corresponding to 2 types of transient slabs under the influence of load combinations CH1 and CH2.

Through the chart, it can be seen that the settlement and curvature of the ground immediately behind the abutment corresponding to the combination of CH1 and CH2 with the type 2 transition slab form is 17% and 30% larger than that of the type 1 transition slab, respectively. However, the deformation curve of the subsoil under the transition slab with the 2nd form is more smooth than that of the 1st transition slab. This is understandable since the 2nd transition slab type is the traditional form, located inside the ground behind the abutment. Although it is more convenient, the deformation of the ground behind the abutment is the deformation of the road surface on which vehicles will move.

With the type 1 transition slab, the raised or lowered soil will affect the working of the transition slab. Therefore, it is necessary to have a measures to limit this influence, to avoid leading to breakage, breaking the transition slab at the position where the mount is directly connected to the abutment. To minimize this adverse effect, it is proposed to add reinforcement steels at the mounting position between the transition slab and the abutment wall.

4. Conclusion

- Increasing the number of spans has a significant effect on the displacement of the curved integral abutment crest; Considering the bridge has the number of 5 spans and the maximum length of the bridge is 150 m with the radius of curvature R = 700 m, the maximum displacement of the abutment crest does not exceed 5.0 cm, corresponding to the maximum displacement of the abutment small and medium demand as recommended by the US.

- With the 2-span curved bridge diagram, the surveyed results show that the D_{xy} translational displacement and αz rotational displacement of the abutment crest are the smallest. The application of the 2-span model with a full-body curved bridge makes the bridge over the road more beneficial in reducing the global deformation during operation.

- The form of the transition slab and the load have a great influence on the deformation of the ground behind the abutment with the monolithic bridge. The type of transition slab combined with pavement - type 1 has many advantages over the traditional form of transition slab buried in the ground.

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NGHIÊN CỨU SỰ LÀM VIỆC CỦA CẦU CONG TOÀN KHỐI TRONG ĐIỀU KIỆN VIỆT NAM

Nguyễn Mạnh Hà, Phạm Tuấn Thanh

Tóm tắt: *Bài báo trình bày kết quả nghiên cứu sự làm việc của kết cấu nhịp cầu cong toàn khối, sự làm việc của nền đất sau mố toàn khối khi thay đổi dạng bản quá độ theo Tiêu chuẩn TCVN 11823-2017. Từ kết quả đó đưa ra những nhận xét và đánh giá về khả năng áp dụng cầu cong toàn khối trong điều kiện Việt Nam.*

Từ khóa: Cầu toàn khối; Midas Civil 2011; Plaxis 8.2; phương pháp phần tử hữu hạn; kết cấu; tương tác kết cấu-nền.

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