RESEARCH THE INFLUENCE OF STIFFNESS OF BEAM ON THE FORCE TRANSMISSION TO THE PONTOON AND ON THE MOMENT IN THE BEAM DUE TO CONCENTRATED LOAD FOR PONTOON-SERAPATE FLOATING BRIDGE

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Abstract

The pontoon-separate floating bridges have many advantages to apply to the construction of civil floating bridges in Vietnam. This article presents the study of the influence of beam stiffness on the force transmission of concentrated load to the pontoon and the bending moment in the beam caused by this load, as a basis for designing civil poonton bridge to carry loads for small tonnage motor vehicles serving rural traffic. The author uses theoretical research methods using SAP2000 software. The results show that the moment in the beam is directly proportional to the stiffness of the beam. The transmission of force to pontoon away from the force application point is also directly proportional to the stiffness of the beam. Initially, the force transmitted to the pontoon near the force application point is inversely proportional to the beam stiffness, and then directly proportional to the beam stiffness.

Keywords: *Floating bridge; continuous girder; separate pontoon; water draft; elastic foundation.*

1. Introduction

Pontoon-separate floating bridges have many advantages and are widely used around the world [1-3]. In Vietnam, this type of floating bridge is suitable for use as civil floating bridge due to many advantages such as: easy to manufacture, taking advantage of available materials such as drums, plastic buoys, pre-fabricated steel beams, simple assembly... In our country today, in some localities, there are no conditions and funds to build permanent hard bridges. Civil floating bridges are still used quite a lot [4, 5]. The bridges that have been built are mainly used for motorbikes, bicycles and pedestrians, so they are mainly built spontaneously with available experience, without systematic design calculations. With the development of current means of transportation, and at the same time based on Technical Standards, Bridge and Rural Road Design Procedures of the Ministry of Transport [6, 7] and actual traffic conditions in rural areas, the requirement is that civil floating bridges need to be able to withstand the load of small motor vehicles

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such as trucks, tractors, agricultural machines, etc. Research on the working characteristics of this type floating bridge is necessary to gradually build a scientific basis to propose a plan for a civil floating bridge that can withstand the load of small motor vehicles for practical application.

2. Scientific basis for establishing calculation models

2.1. Overview of pontoons- separate floating bridge

Pontoon-separate floating bridges has the structure as shown in Fig. 1 [8]. The bridge consists of main beams placed on bridge seats which are pontoons.

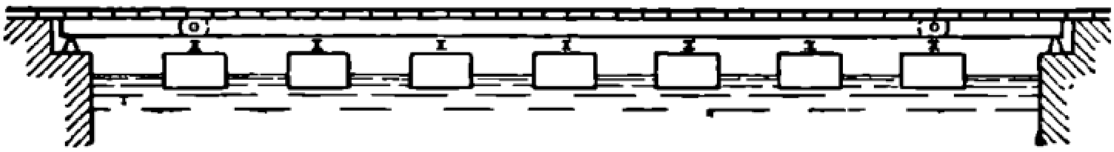

Fig. 1. Diagram structure of a pontoon-separate floating bridge.

In our country, pontoon-separate floating bridges are often used to make civil floating bridges, mainly carrying light loads such as pedestrians, motorbikes.

The theory of calculating the force of the load transmitted to the pontoon and the moment of the beam due to the load caused by this type of floating bridge can be summarized as follows [8, 9]:

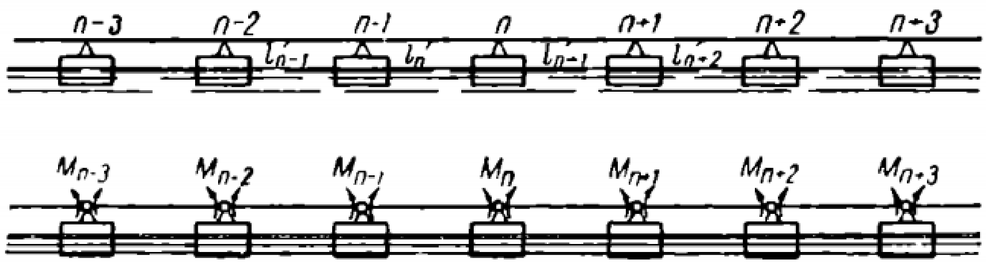

Fig. 2. Calculation diagram of pontoon-separate floating bridges.

The dependence of the displacement (draft) of the pontoon δ_n on the reaction force A_n (downward force) of the pontoon is:

$$\delta_n = \varepsilon_n \cdot A_n \tag{1}$$

where δ_n is the draft of the pontoon, A_n is reaction force of the pontoon (support reaction), ε_n is called the pliability of elastic supports, or the displacement value of the pontoon submerged in water in the vertical direction (water draft) due to a force of 1 ton acting directly on it. Where γ is the specific gravity of water, F_n is the waterline area of the pontoon. In case the pontoon is rectangular:

$$\varepsilon_n = \frac{1}{\gamma \cdot F_n} \tag{2}$$

The problem of calculating floating bridges of this type leads to the problem of continuous beams on elastic supports. The 3 moment equation of a continuous beam on an elastic support is as follows:

$$M_{n-1} \cdot \tau_{n,n-1} + M_n \cdot (\tau_{n,n}^{tr} + \tau_{n,n}^{ph}) + M_{n+1} \cdot \tau_{n,n+1} + \frac{\delta_{n+1} - \delta_n}{l_{n+1}} - \frac{\delta_n - \delta_{n-1}}{l_n} + (\tau_n^{0.tr} + \tau_n^{0.ph}) = 0 \tag{3}$$

M_n are moments at the n^{-th} support. The reaction force of the n^{-th} support is synthesized from the reaction force due to the load acting on the base system (beam with pin-joint at the cross-section on supports) and the reaction force from the bearing moment:

$$A_n = A_n^0 + \frac{M_{n+1} - M_n}{l_{n+1}} - \frac{M_n - M_{n-1}}{l_n} \tag{4}$$

Based on formula (1), it is deduced:

$$\delta_n = \varepsilon_n \cdot \left[A_n^0 + \frac{M_{n+1} - M_n}{l_{n+1}} - \frac{M_n - M_{n-1}}{l_n} \right] \tag{5}$$

Put the values δ_{n-1}, δ_n, δ_{n+1} into Eq. (3) and then put them into the 5-moment equation form:

$$M_{n-2} \cdot \theta_{n,n-2} + M_{n-1} \cdot \theta_{n,n-1} + M_n \cdot \theta_{n,n} + M_{n+1} \cdot \theta_{n,n+1} + M_{n+2} \cdot \theta_{n,n+2} + \theta_{n,p} = 0 \tag{6}$$

where the coefficients $\theta_{n,n}, \tau_{n,n}$ are calculated as follows:

$$\theta_{n,n-2} = \frac{\varepsilon_n - 1}{l_{n-1} \cdot l_n}; \theta_{n,n-1} = \tau_{n,n-1} - \left[\frac{\varepsilon_{n-1}}{l_n} \left(\frac{1}{l_{n-1}} + \frac{1}{l_n} \right) + \frac{\varepsilon_n}{l_n} \left(\frac{1}{l_n} + \frac{1}{l_{n+1}} \right) \right]; \theta_{n,n+2} = \frac{\varepsilon_{n+1}}{l_{n+1} l_{n+2}} \tag{7}$$

$$\tau_{n,n-1} = \frac{l_n}{6EI_n}; \quad \tau_{n,n+1} = \frac{l_{n+1}}{6EI_{n+1}} \tag{8}$$

Apply boundary conditions, alternately substitute the values n = 0, 1, 2... to calculate the coefficients according to Eq. (7) and Eq. (8), then substitute the coefficients into Eq. (6) to establish get the system of unknown equations which are moments M_0, M_1, M_2... Use the Gauss method to solve this system of equations, you will get the unknowns to be found M_0, M_1, M_2... and according to the formulas above is the way to solve the problem of beams on elastic supports based on mechanical knowledge, using the force method, which takes a lot of time and effort.

Along with the development of science and technology and computers, some structural calculation softwares can now model the problem of beams on elastic supports. In the article, the author uses SAP2000 software to model and calculate the proposed problem [10].

2.2. Select a floating bridge to survey

Select the floating bridge for investigation as follows: The middle part of the river of the floating bridge consists of 6 spans, the transition part with the shore has 1 span on each side, the length of the transition spans and the span of the middle part of the river are $L = 6\,\text{m}$, based on the requirement that this type is determined to be used for rural traffic, a span of 6 m is relatively suitable, combined with reference experience in [8]. The number of spans is random. The edge span and middle span are connected together by pin-joint.

Continuous beams are made from pre-fabricated shaped steel according to Vietnamese standard TCVN 5709:2009 [10]. The beam cross-sections change with increasing height (I100 × 50; I150 × 75; I200 × 100; I250 × 125; I300 × 150; I350 × 150; I400 × 150; I450 × 175), corresponding to increasing beam stiffness. The bridge is subjected to the load of two concentrated forces Q = 10 kN distributed in the middle span of the bridge. The rectangular pontoon has a waterline area of $F = 1$ m^2.

Some assumptions to build the calculation model: Consider the problem in flat geometric 2-dimensional space, not 3-dimensional space. The beam is considered continuous and the cross-section remains constant. The beam is placed on the pontoon at one point in the center of the pontoon. Concentrated load Q is dead load. Does not take into account the dynamic effects of loads. The load is placed at the exact center of the bridge, no eccentric load is considered. Ignore the impact of water waves and the effect of water flow velocity on the pontoon. Both ends of the bridge are hard abutments.

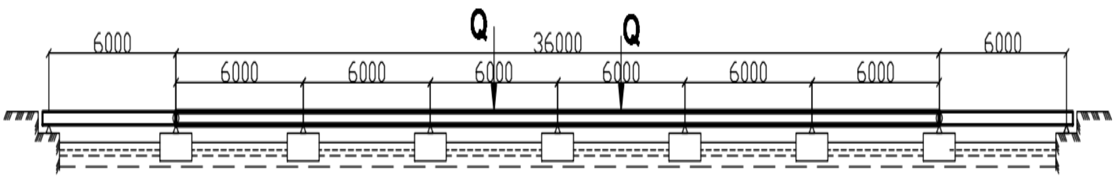

Fig. 3. Plan of floating bridge used for survey.

In the article, SAP2000 software is used for modeling and calculation. The pontoons are modeled as elastic bearings with elastic coefficient *k*.

$$k = \frac{1}{\varepsilon} = \gamma \cdot F = 10 \cdot 1 = 10 \frac{\text{kN}}{\text{m}}$$

Continuous beams use frame elements. Below is model of pontoon-separate floating bridges used for calculation on SAP2000 software.

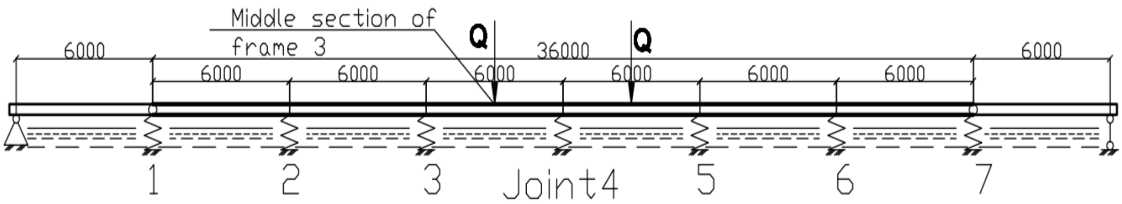

Fig. 4. Model of pontoon-separate floating bridges used for calculation.

2.3. Results

Survey results for the model of pontoon-separate floating bridges with parameters as in section 2.1 are shown in the tables and graphs below.

Table 1 shows the value of internal force at the cross section in the middle of the span of the beam corresponding to the stiffness of the beam obtained from SAP2000 software. From the data in Table 1, build a graph of the dependence of bending moment at the mid-span cross section of the beam on the stiffness of the beam, moment value of the middle section of frame number 3.

Table 1. Value of internal force at the cross section at the center of the beam's span 3 corresponding to the stiffness of the beam

Order	Section I	Stiffness	Element Forces - Frames							
			Frame	Out put Case	Axial force	Shear force		Torsional moment	Bending moment	
		EI	-	-	P	V2	V3	T	M2	M3
		kN.m^2	Text	Text	kN	kN	kN	kN.m	kN.m	kN.m
1	100 × 50	350	3	HT	0	-5.55	0	0	0	13.59
2	150 × 75	1638	3	HT	0	-6.47	0	0	0	22.12
3	200 × 100	4340	3	HT	0	-7.00	0	0	0	32.98
4	250 × 125	10360	3	HT	0	-7.51	0	0	0	46.24
5	300 × 150	18960	3	HT	0	-7.84	0	0	0	55.54
6	350 × 150	30400	3	HT	0	-8.05	0	0	0	61.69
7	400 × 150	48200	3	HT	0	-8.21	0	0	0	66.36
8	450 × 175	78400	3	HT	0	-8.33	0	0	0	70.06

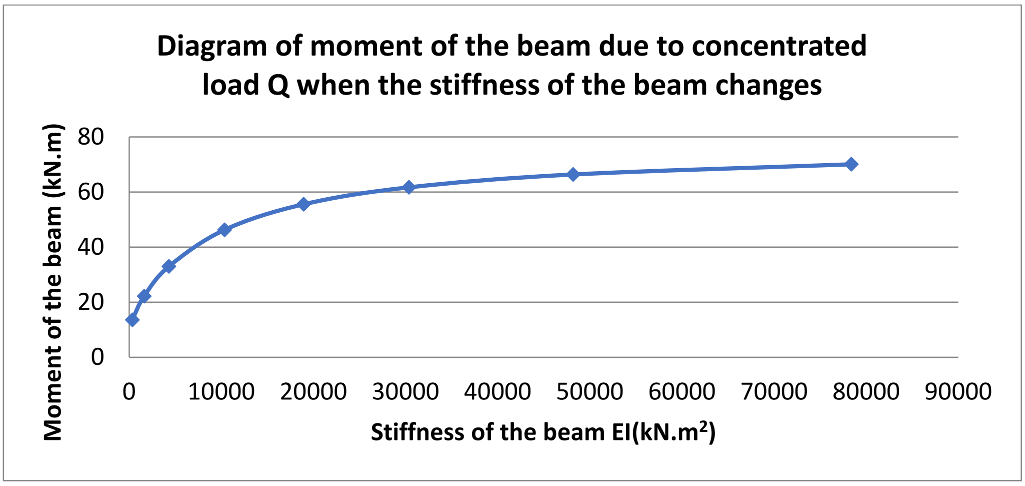

Fig. 5. Diagram of moment of the beam due to concentrated load Q when the stiffness of the beam changes.

From the chart above, it can be seen that, for a determined value of beam length, when the stiffness of the beam increases, even if the value of concentrated load Q does not increase, the bending moment of the beam due to this load increases significantly.

Table 2 shows the value of the reaction force of the pontoon due to the self weight of the beam (S.W) corresponding to the stiffness of the beam, value of reaction force at support (joint) number from 1 to 7.

Table 2. Pontoon reaction due to self weight of the beam corresponding to beam stiffness

Order	Section I	Stiffness EI ($kN.m^2$)	Output Case	Support reactions A_n (kN)						
				Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	Joint 7
1	100 × 50	350	S.W	0.46	0.51	0.50	0.49	0.50	0.51	0.46
2	150 × 75	1638	S.W	0.94	1.00	1.01	1.01	1.01	1.00	0.94
3	200 × 100	4340	S.W	1.45	1.51	1.53	1.53	1.53	1.51	1.45
4	250 × 125	10360	S.W	2.17	2.22	2.25	2.26	2.25	2.22	2.17
5	300 × 150	18960	S.W	2.76	2.81	2.84	2.84	2.84	2.81	2.76
6	350 × 150	30400	S.W	3.36	3.40	3.43	3.43	3.43	3.40	3.36
7	400 × 150	48200	S.W	4.14	4.17	4.19	4.20	4.19	4.17	4.14
8	450 × 175	78400	S.W	5.28	5.31	5.33	5.33	5.33	5.31	5.28

Table 3 shows the value of the reaction force of the pontoon due to the load Q corresponding to the stiffness of the beam, value of reaction force at support (joint) number from 1 to 7.

Table 3. Value of pontoon reaction due to load Q corresponding to beam stiffness

Order	Section I	Stiffness EI (kN.m^2)	Output Case	Support reactions A_n (kN)						
				Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	Joint 7
1	100 × 50	350	Load Q	-0.64	0.77	5.41	8.89	5.41	0.77	-0.64
2	150 × 75	1638	Load Q	-0.75	1.96	5.26	7.05	5.26	1.96	-0.75
3	200 × 100	4340	Load Q	-0.18	2.37	4.82	5.98	4.82	2.37	-0.18
4	250 × 125	10360	Load Q	0.68	2.58	4.24	4.97	4.24	2.58	0.68
5	300 × 150	18960	Load Q	1.32	2.68	3.83	4.31	3.83	2.68	1.32
6	350 × 150	30400	Load Q	1.76	2.73	3.55	3.89	3.55	2.73	1.76
7	400 × 150	48200	Load Q	2.09	2.77	3.34	3.58	3.34	2.77	2.09
8	450 × 175	78400	Load Q	2.35	2.80	3.17	3.33	3.17	2.80	2.35

Table 4 shows the value of the reaction force of the pontoon due to the total load (self weight of the beam and load Q) corresponding to the stiffness of the beam.

Table 4. Value of pontoon reaction due to total load corresponding to beam stiffness

Order	Section I	Stiffness EI (kN.m^2)	Output Case	Support reactions An (kN)						
				Joint 1	Joint 2	Joint 3	Joint 4	Joint 5	Joint 6	Joint 7
1	100 × 50	350	Total	-0.18	1.29	5.92	9.39	5.92	1.29	-0.18
2	150 × 75	1638	Total	0.18	2.97	6.27	8.0	6.27	2.97	0.18
3	200 × 100	4340	Total	1.26	3.88	6.36	7.52	6.36	3.88	1.26
4	250 × 125	10360	Total	2.85	4.80	6.5	7.23	6.5	4.80	2.85
5	300 × 150	18960	Total	4.09	5.49	6.67	7.16	6.67	5.49	4.09
6	350 × 150	30400	Total	5.13	6.14	6.98	7.33	6.98	6.14	5.13
7	400 × 150	48200	Total	6.23	6.95	7.53	7.78	7.53	6.95	6.23
8	450 × 175	78400	Total	7.61	8.12	8.50	8.66	8.50	8.12	7.64

From data of tables 2, 3, 4, it can be seen that, for support (joint) number 1: The value of the reaction force of pontoon A_n due to self weight of the beam, due to the load

Q transmitted to the pontoon, is proportional to the beam stiffness. And as the beam stiffness increases, total load (self weight of the beam and load Q) transmitted to the pontoon increases.

From the data in tables, build a chart showing the dependence of the force transmitted to the pontoon of the self weight, of the load Q and of the total load on the stiffness of the beam (Fig. 6) for support (joint) number 1. The rules of force distribution on support number 2 is similar to support number 1.

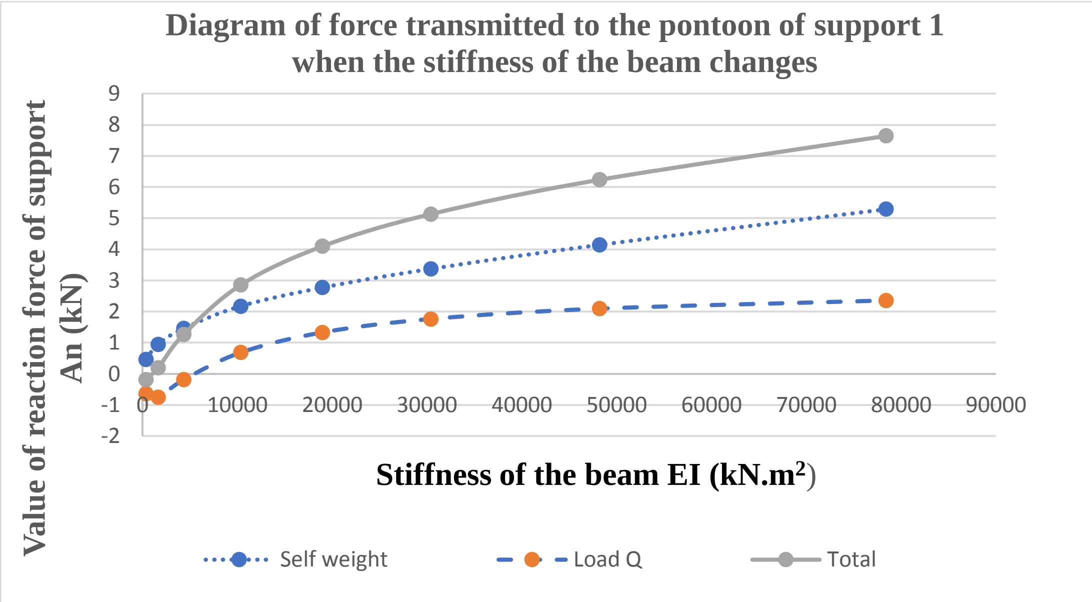

Fig. 6. Diagram of force transmitted to the pontoon of support 1 when stiffness of beam changes.

From data of tables 2, 3, 4, it can be seen that, when the stiffness of the beam increases, (that is, the weight of the beam also increases), for support (joint) number 4: The value of the reaction force of pontoon A_n due to self weight of the beam transmitted to the pontoon, is proportional to the beam stiffness. But even though the load Q remains unchanged, the force transmitted to each pontoon from that load Q decreases significantly. This means that the force from load Q transmitted to the pontoon is inversely proportional to the stiffness of the beam. This problem is due to the force Q transmitted down the pontoon approaching more evenly. Therefore when the beam stiffness increases, the force transmitted to each pontoon of the total load initially decreases, then increases again.

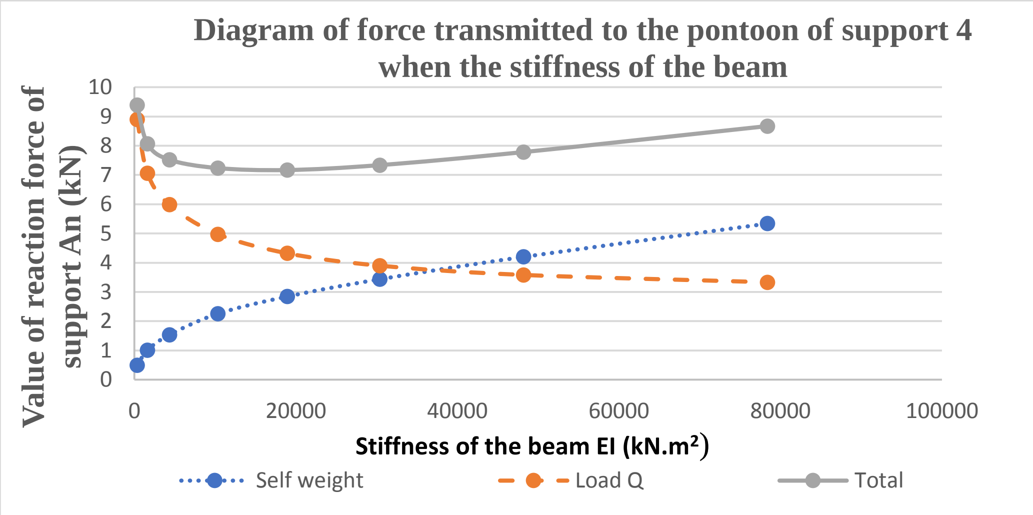

Fig. 7. Diagram of force transmitted to the pontoon of support 4 when stiffness of beam changes.

Build a chart showing the dependence of the force transmitted to the pontoon due to the total loads on the stiffness of the beam (Fig. 7) for support (joint) number 4. The rules of force distribution on support number 3 is similar to support number 4.

Symmetrical supports such as support No. 1 and No. 7, No. 2 and No. 6, No. 3 and No. 5 have the same force transmission rules. Due to the limited scope of the article, the author provides an analysis of the reaction force at support No. 1 and support No. 4, which are cases where the load transmitted down has different rules.

Thus, through the chart above, it is possible to find the optimal value of the beam cross-section according to the criterion of pressure transmitted to each pontoon. The optimal beam cross-section is the beam cross-section that minimizes the pressure of the total load transmitted to each pontoon, thereby saving materials for making the float.

3. Conclusion

From the above survey results, it is seen that for pontoon-separate floating bridges, when the stiffness of the beam increases, even though the concentrated load Q does not increase, the bending moment of the beam due to this load causes a significant increase.

When the stiffness of the beam increases, for some supports, the self weight transmitted to the pontoon increases, the load Q transmitted to the pontoon also increases and therefore the total force transmitted to the pontoon also increases.

But for some other supports, when the stiffness of the beam increases, the self weight of beam transmitted to the pontoon increases, but the load Q transmitted to the pontoon decreases, leading to a decrease in the total force transmitted to the pontoon, then increased again

The vehicle load can be considered the concentrated forces transmitted down at the position of the wheels. From there, it is possible to build a scientific basis to design a floating bridge to carry the load of small motor vehicles to serve rural traffic.

Due to the limited scope of the article, in addition to the issue of the impact of beam stiffness on the transmission of force to the pontoon and on the moment in the beam caused by concentrated loads mentioned above, the author has not gone into the calculation and solution many other problems when studying pontoon-separate floating bridges. The author hopes to be able to discuss these issues with colleagues and readers for further improvement.

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NGHIÊN CỨU ẢNH HƯỞNG ĐỘ CỨNG CỦA DẦM ĐẾN TRUYỀN LỰC XUỐNG PHAO CẦU VÀ MÔ MEN TRONG DẦM DO TẢI TRỌNG TẬP TRUNG CHO LOẠI DẦM LIÊN TỤC TRÊN CÁC PHAO RIÊNG BIỆT

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Tóm tắt: Cầu phao dạng dầm liên tục trên các phao riêng biệt có nhiều ưu điểm để áp dụng vào xây dựng cầu phao dân sinh ở Việt Nam. Bài báo trình bày việc nghiên cứu ảnh hưởng của độ cứng dầm đến sự truyền lực của tải trọng dạng lực tập trung xuống phao và mô men uốn trong dầm do tải trọng này gây ra, làm cơ sở cho việc nghiên cứu phương án cầu phao dân sinh chịu tải trọng xe cơ giới trọng tải nhỏ phục vụ giao thông nông thôn. Tác giả sử dụng phương pháp nghiên cứu lý thuyết bằng cách sử dụng phần mềm SAP2000. Kết quả nhận được cho thấy mô men trong dầm tỉ lệ thuận với độ cứng của dầm. Sự truyền lực xuống các phao cách xa điểm đặt lực cũng tỉ lệ thuận với độ cứng của dầm. Ban đầu, lực truyền xuống phao gần điểm đặt lực tỉ lệ nghịch với độ cứng dầm, còn sau đó tỉ lệ thuận với độ cứng dầm.

Từ khóa: *Cầu phao; dầm liên tục; phao riêng biệt; mớn nước; nền đàn hồi.*

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