Int. J.MAr.Sci.Eng., 3(3), 125-132, Summer 2013
ISSN 2251-6743

Structural analysis of the deck of access bridges in offshore docks under dynamic loading of moving heavy vehicles (Case study: 10 feet concrete deck with prefabricated beam, under the passage of 125-ton bogie)

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Received 1 February 2013; revised 3 March 2013; accepted 30 May 2013

ABSTRACT: Ports are the most important economic, political and military bottlenecks. This puts shoreline structures (port) in the class of important structures and they have a crucial role in the countries' life. Pile and deck wharf and their access bridges and offshore deck (jetties), are one of the parts which are supplier of coupling between the land and the waterfront. Correct and exact estimation of loads acting on individual structures leads to more accurate and more economical design. To design waterfront deck, it is necessary to estimate the amount of reaction generated in the deck by live loads due to the crossing of the machines over it. To more accurate assessment the effect of moving vehicle passing on the deck, the dynamic analysis is used to calculate the response generated in the deck. The modeling of the vehicle moving on an access bridge of pier piles and deck with the beam element-capturing method, and the D'Alembert and balance principle are used to write the governing differential equation. The deck is also modeled in the form of Euler-Bernoulli beam, with a uniform cross-section. Dynamic load modeling for dynamic analysis of the deck is done by MATLAB program. The main output of this research is to answer the question, that the moving vehicle passing with heavy cargo, with unconventional weight can cause what reactions in the deck? Depending on the type of deck structures and military vehicles, unique results can be obtained including a new deck design, deck strengthen for existing services and changes in specific cargo trailers for safe passing on the deck.

Keywords: *Pile and deck wharf; Access Bridge; Dynamic load; Dynamic analysis*

INTRODUCTION

The ports are built based on different objectives like Political and aquatic border (military port), trade and economic issues (ports), access to marine resources (fishing port), multiple ports for a combination of purposes. Correct and exact evaluation of loads imposed on each parts of port results in more accurate and economical design. To design access bridge, when the pass way is for heavy vehicles, firstly the effect of passing these loads on decks should be analyzed to make exact and correct analysis. Pile and deck open wharf, are made of two parts: (i) infrastructures and (ii) superstructure where each part are loaded and designed proportional to the loads on them. To design decks, generally, loading procedures for bridges are used. If wharf decks or access bridges is to withstand special vehicles weight, the deck should be designed for these loads and cars. The only difference of designing these decks is to evaluate the effect of passing loads on decks and other stages, is like ordinary decks. Dynamic effect of passing vehicles on decks is related to many parameters as deck properties and vehicles passing on. Since ship berthing is not done along the access bridge, thus dominant load on access bridge is due to live load of passing vehicles and amount of the effects depends on the load on deck by each tire of the vehicle, the number of axes, the speed of vehicles and deck dynamic parameters such as the mass per unit length of deck.

This paper studies moving load effect on marine access bridges. The main significance and difference between the present work and the available literature is that typically in the design codes an impact factor

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is applied to the load and the load is modeled as a static load; however, the present research is innovative in a way that it uses a MATLAB code considers a real dynamic impact factor to model the moving load.

MATERIALS AND METHODS

1. Modeling methodology of vehicles and deck

The modeling methodology of vehicles and deck generally is applied in moving state on the deck of roads bridges. The moving of vehicles on wharf deck is similar to moving vehicles on the decks of land bridges.

• *Modeling of vehicles as moving load*

The simplest method of modeling vehicles is to model them as moving load (Fig.1); the primary works on the realm of moving vehicles on deck are e.g. Fryba (1972) and Delgado *et al.* (2009). In this kind of modeling, because of ignoring the effect of vehicles inertia compared to deck, the contact force between hypothetical vehicle and the deck is a constant. The accurateness of solving depends on the mass-of-vehicle-to-deck ratio, and this problem gets more close to real state as reducing this rate, and on the contrary, with the enlargement of the mass of the vehicle to deck, the deck displacement responses are far from reality. Two factors of moving vehicle are effective on deck. One of them is the force of gravity and the other one is inertia on vehicles. Each one of these factors, are in the direct relation with vehicles weight. When the weight of moving vehicle is lower than deck weight, thus the inertia, generated by passing moving vehicle would be low. In this state the vehicle could be modeled as moving load. The governing equation on wharf deck that is used in moving load method is presented by Yang *et al.* (2004a).

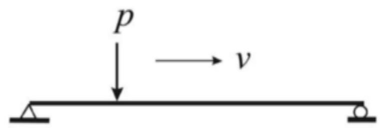
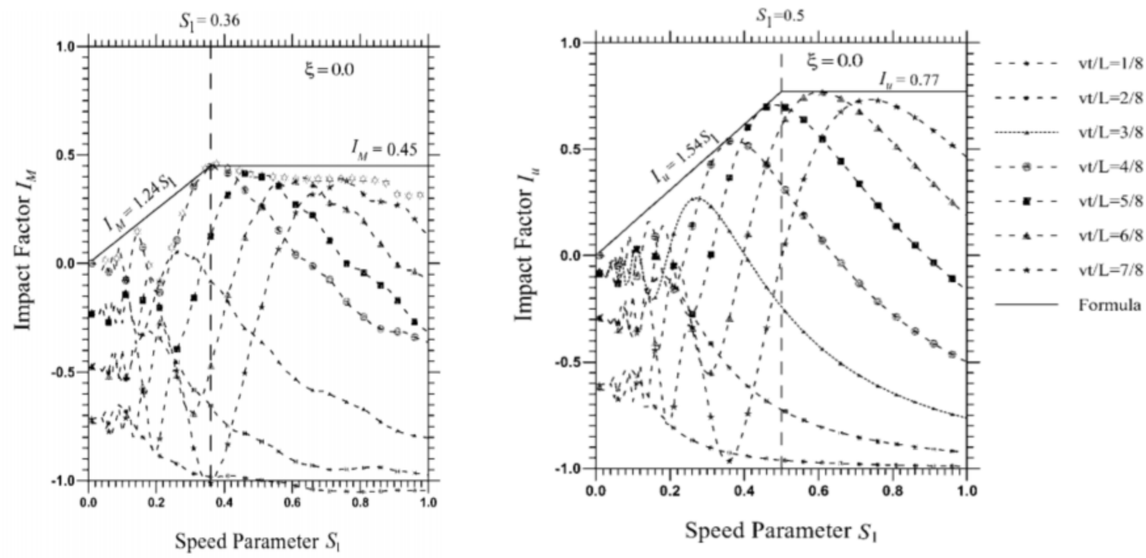


Fig. 1: The model of moving load

• *Deck modeling as Bernoulli – Euler beam and with a uniform cross-section*

After solving dominant differential equations (which are explained in the next section) and defining dimensionless parameter of speed (velocity) as $S_n = \frac{n\pi v}{\omega_n L}$ in which v indicates speed of movement meters per second, L, is the length of span in meter and ω_n is the nth beam vibration frequency. The amount of impulse and moment displacement coefficients for simple double beam at different speeds during the passage of individual unit load are shown in Fig. 2. As it is seen in Fig. 2, the impulse coefficient for the amount of displacement and moment is different and the speed of movement, has the direct effect on reactions and it shows the importance of dynamic analysis to evaluate vehicles movement on bridge and its comparison with static analysis.



(a) (b)

Fig. 2: The diagram for impulse coefficient at the mid-span versus velocity dimensionless parameter (a) moment (b) displacement (Yang *et al.*, 2004b).

2. The load of passing vehicles on deck from regulation point of view

Loading bridges and the pavement of rail road and asphalt ways should be with regard to the passing loads. Thus, amount of deck design loads, should cover all loads of the vehicles passing on the bridge. In Iran, the regulation of loading of bridges (Publication 139, 2007) and (Publication 300, 2006), published by Planning and Management Organization, is the base of loading of bridges which are used in freeways or rail roads. In this regulation live loads resulted from passing vehicles from deck, located in high ways, are divided into three types.

1. First type loads which are called ordinary loads show heavy axle of trucks and cars which are generally passing on decks.
2. Second type load in bridge loading regulation is in the kind of load in amount of eight tones which impose on a 30 cm^2 surface area and it could exist in all locations of pass way.
3. The third type loads are (i) tank load with the weight of 70 tones, and (ii) tank trailer load which is used to carry tank with six axes with total weight of 90 tones.

For the third type, the 90 tones tank trailer, in the width of bridge, only one trailer and in the length, maximum two trailer with the minimum distance between tires of trailer, in direction of trailer width, equal to 3.1 meter, the minimum distance of tires to pavement edge is 0.5 m. The schematic model of trailer loading is shown in Fig. 3.

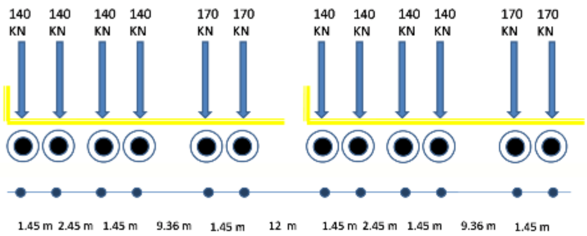


Fig. 3: Schematic model of trailer loading

In Iran bridges loading regulation (Publication 139, 2007) it is declared that to pass loads with the weight more than certificated one, the certification should be taken. To seek agreement of officials to pass loads more than above limitation stress analysis is necessary.

3. Impact coefficient (factor)

The movement of car on deck with high way normal speed, will create more reaction than static state on bridge. The amount of increase in reaction is called impact factor. The dynamic effect, not only is important in passing vehicles on deck, but it is equally important on any structure which it's loading time is short. From theory point of view, amount of created reaction because of impulse, the ability of reaction in structure two times static situation is available; but, the amount of load on deck by vehicle is lower that amount which is created in sudden impulse. Thus impulse factor is lower than 2 and higher than 1 (Chopra, 2001). In addition to impulse load that is exerted on the deck by the vehicle, the vehicle vibrates on it's own suspension system (spring and dampers between frame and wheel components) relative to deck. Thus, amount of reaction on deck is directly related to car mass and deck. Impulse factor depends on the properties of passing vehicle and deck. But impulse factor is imposed as the reaction on bridge on static analysis. It is important that the impulse factor, used in regulations, contain properties of the moving vehicle and the deck. Next, impulse factors used in some regulations are presented. Impulse factor could be defined as follows:

$$DLA = \frac{D_{\text{dyn}} - D_{sta}}{D_{sta}} \quad (1)$$

In general form, impulse factor of $DLA + 1$, transforms the value of static reaction to the highest dynamic reaction. The impulse factor depends on different reactions such as moment, shear, displacement and stress. Based on research (O'Connor and Pa, 2000), amount of impulse factor has a more significant dependency on displacement, compared to other reactions such as stress, velocity, etc., thus, regulations use displacement dependent impulse factor for other parameters. Most of regulations like (AASHTO, 2010) have presented impulse factor based on span. In Fig. 4, suggested impulse factors by different regulations are presented to compare.

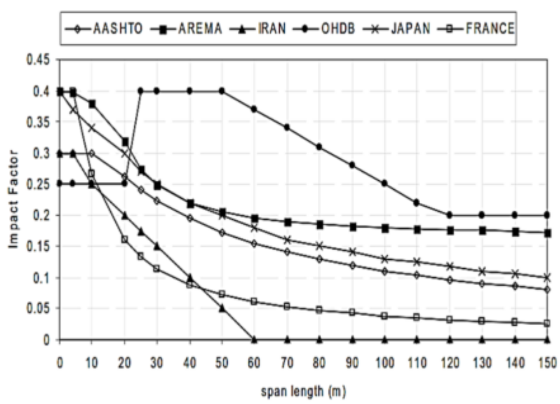


Fig. 4: The Comparison of different regulations impulse factors (Ronagh and Moghimi, 2007)

4. Obtaining dominant relations and solving them in movement of load model of vehicle on deck

two main factor in moving car on deck are dominant. One is gravity and the other is inertia of vehicle. Each one of these factors has direct correlation with vehicle weight. When vehicle weight compared with deck weight is lower, the created inertia one deck because of passing vehicle would be low and as this rate be low, the inertia would be low too. In this situation, the vehicle could be modeled as a moving load.

solving the problem of dynamic load using moods superposition method

In Fig. 1, a simple-ended beam was shown in which, a load with constant amount of p, is moving on it with constant speed of vehicle. Governing differential equation on the simple-ended beam is as is shown in Fig. 5.

Beam differential equation Fig.(5-a) could be written in below mentioned form considering an element as shown in Fig. (5-b) and writing balance in vertical direction as follows (Abu-Hilal, 2003):

$$V(x,t) + p(x,t)dx - \left(V(x,t) + \frac{\partial V(x,t)}{\partial x}dx\right) - f_I(x,t)dx = 0 \qquad (2)$$

In equation (2), $f_I(x,t)$ the amount of element of inertia considered which is according to D'Alembert principle with positive amount in inverse direction of positive mark for movement.

$$\frac{\partial^2}{\partial x^2}\left(EI(x)\frac{\partial^2 v(x,t)}{\partial x^2}\right) + m(x)\frac{\partial^2 v(x,t)}{\partial t^2} = p(x,t) \qquad (3)$$

flexural deformation (Euler-Bernoulli beam theory)

In Fig. 6, an element with length of *L*, volume unit mass of ρ, elastic modulus of *E*, cross section of *A* and inertia moment of *I* is shown. Vertical movement along the element can be written as a function of end displacement and rotation as in equation (4).

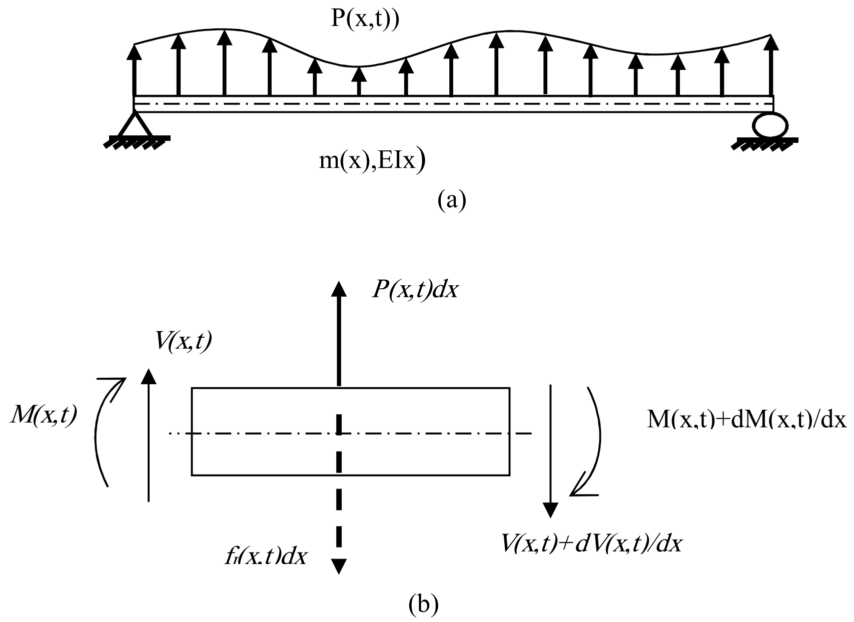


Fig. 5-(a) Base beam under dynamic loading; (b) an element of length dx with imposed loads diagram

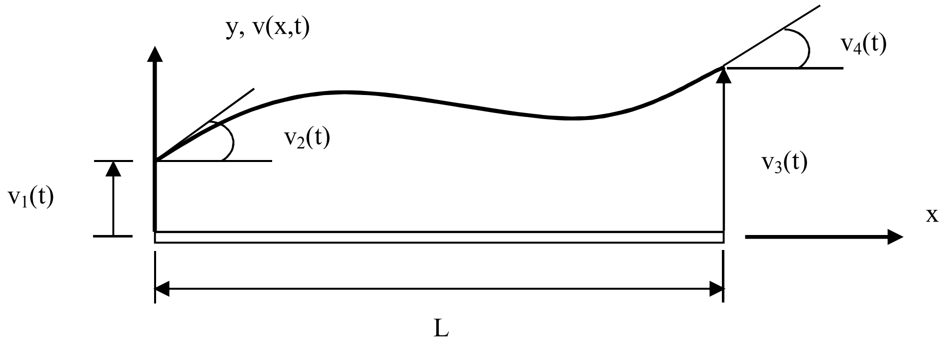


Fig. 6: Uniform element under vertical motion

$$v(x,t) = \sum_{i=1}^{4} \psi_i(x) v_i(t) \quad (4)$$

In the conditions in which four functions are attained for displacement interpolation across the element using quadrate freedom of element ties, should satisfy below mentioned critical condition:(Clough and Penzien, 1993).

$$\begin{aligned} &\psi_1(0) = 1, && \psi_1'(0) = \psi_1(L) = \psi_1'(L) = 0 \\ &\psi_2'(0) = 1, && \psi_2(0) = \psi_2(L) = \psi_2'(L) = 0 \\ &\psi_3(L) = 1, && \psi_3(0) = \psi_3'(0) = \psi_3'(L) = 0 \\ &\psi_4'(L) = 0, && \psi_4(0) = \psi_4'(0) = \psi_4'(L) = 0 \end{aligned} \quad (5)$$

To obtain considered functions, it is enough that with static loading at beginning and ending of element using shear and unit moment and closing freedom degrees of other function, to obtain considered amount. Hardness matrix and the mass of an element with length of L, volume, unit mass of P, elastic module of E, cross section of A, inertia moment of I as equation (6), could be obtained.

$$K = \frac{EI}{L^3}\begin{bmatrix} 12 & 6L & -12 & 6L \\ & 4L^2 & -6L & 2L^2 \\ & & 12 & -6L \\ sym & & & 4L^2 \end{bmatrix}$$

$$m = \frac{\rho AL}{420}\begin{bmatrix} 156 & 22L & 54 & -13L \\ & 4L^2 & 13L & -3L^2 \\ & & & -22L \\ sym & & 156 & 4L^2 \end{bmatrix} \quad (6)$$

5.The dynamic analysis to obtain created reaction on deck imposed by passing bogie carrying 108 ton tank:
In this part, the steps of structure analysis of a deck under passing of Bogie is presented. This tank is 108/86 ton which is selected from NATO classification. In Fig. 7 the schematic form of axles loads and their distance from each other on trailer which holds passing tank, is shown. As it is shown, the tank and trailer weight is totally 125.16 ton.

For dynamic analysis, deck properties including mass per unit length, bending stiffness, and span length are estimated based on architectural plans. Mass per unit length is 15000 kg/m, modulus of elasticity 25×10^9 Pa, span length 10 meters and maximum speed is assumed 150 km/hr.

RESULTS AND DISCUSSION

After the completion of plan, the results of dynamic structure analysis would be as below. The Fig. 8, is the maximum movement at the middle of mouth in the limitation of vehicle speed (Fig. 7). As it is shown, the diagram does not change linearly by increasing speed and maximum and minimum values are relative. The relative maximum show that moving vehicle's speed equals to deck resonance speeds.

Fig. 9, in fact is obtained from Fig. 8 with dividing maximum displacement of deck midpoint to static response (1 m/sec) and extracting one out of the resulting value.

Figs. 10 and Fig. 11 respectively, are the amount of maximum moment and shear in each section of deck during the vehicle passing with equivalent static speed (1 m/s).

In the computer program, there are some conditions that in the highest speed of vehicle, the highest displacement, speed and acceleration could be obtained based on time. The following diagrams (Figs. 12 to 16) show these outputs of the computer program.

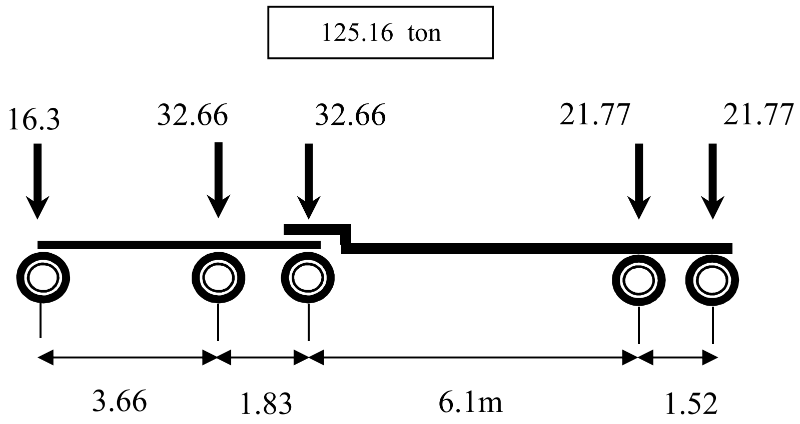


Fig.7: Schematic model of Bogie trailer and tank total weight 125 ton

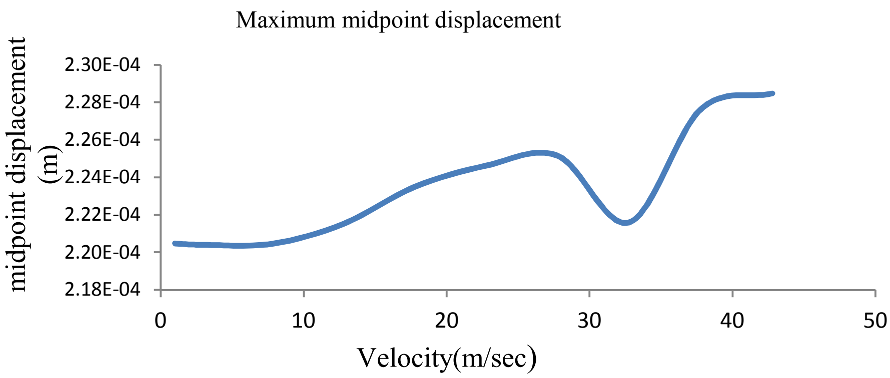


Fig. 8: Maximum displacement of midpoint in considered speed range due to 125 ton tank trailer passing

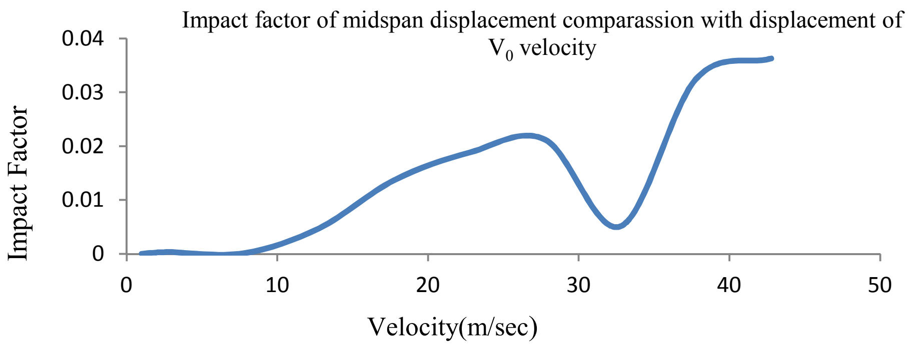


Fig. 9: Maximum impact factor of midpoint in considered speed range due to 125 ton tank trailer passing

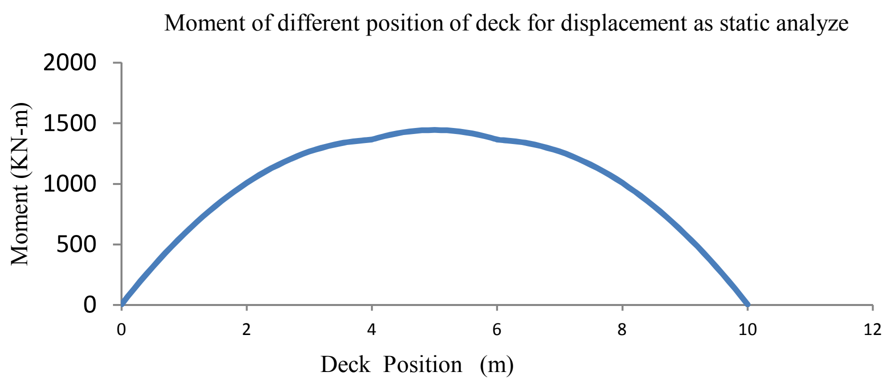


Fig.10: Maximum moment on different parts of deck in static analysis speed under the load of 125 ton tank trailer.

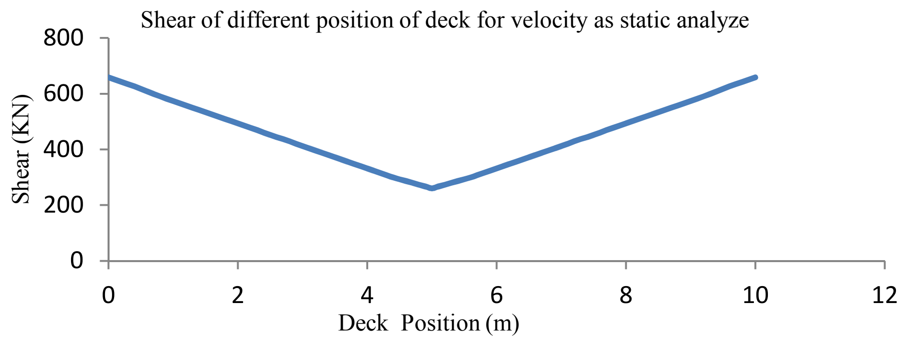


Fig.11: Maximum shear on different parts of deck in static analysis speed under the load of 125 ton tank trailer

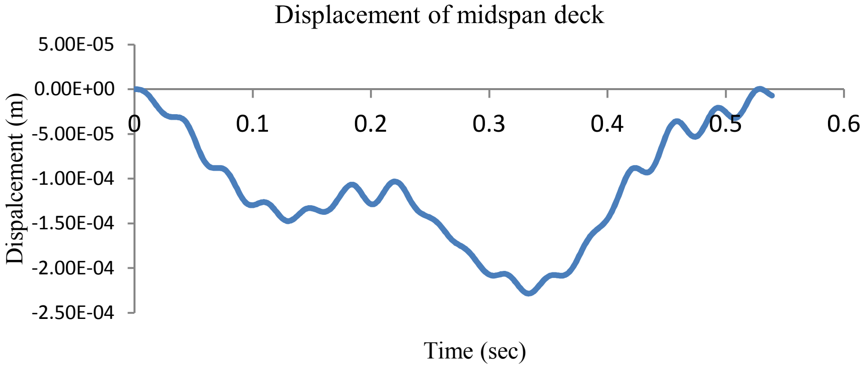


Fig. 12: The displacement of mid span deck in the biggest speed under 125 ton trailer passing on

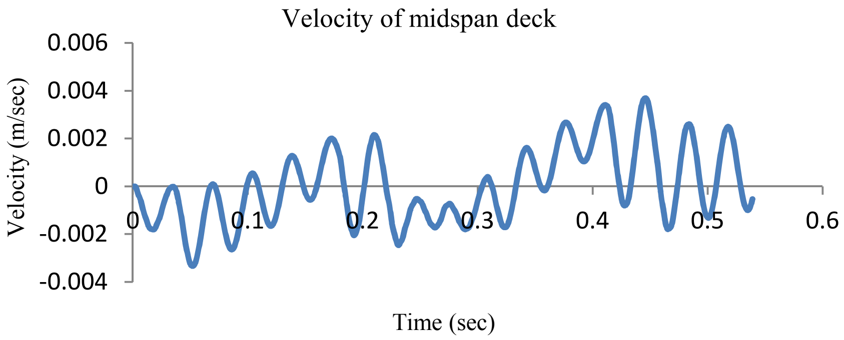


Fig. 13: The speed of mid span deck mouth in the biggest speed under 125 ton trailer passing on

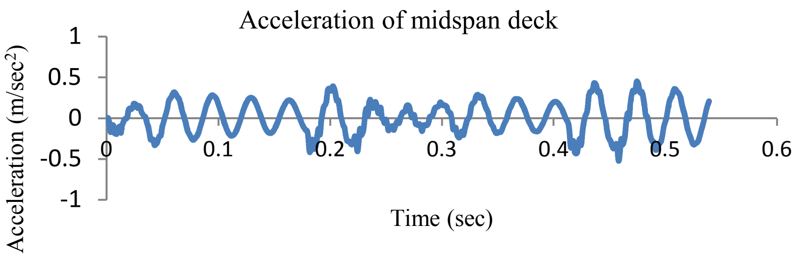


Fig. 14: The acceleration of mid span deck in the biggest speed under 125 ton trailer passing on

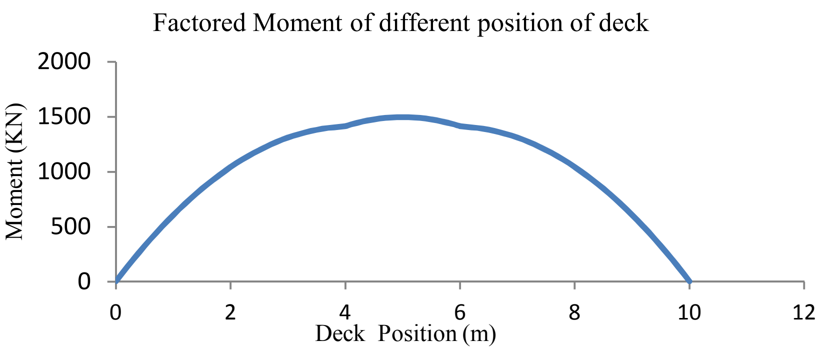


Fig. 15: The maximum factored moment of different position of deck in the biggest speed under 125 ton trailer passing on

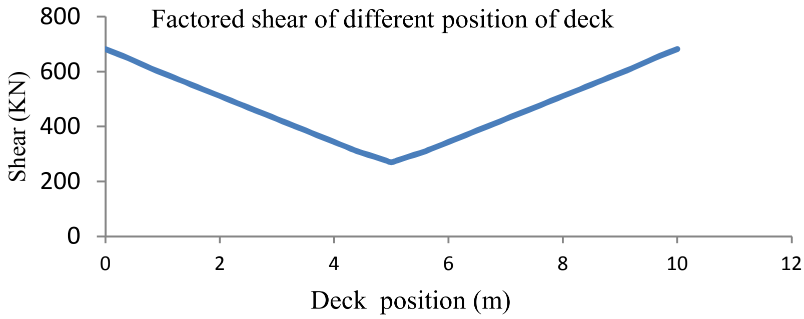


Fig. 16: The maximum factored shear of different position of deck in the biggest speed under 125 ton trailer passing on

Of course, loads should have standard and typical definitions according to the most extreme cases that may occur during the service life of the structure. The loading shown in Fig. 7 represents such an extreme case. It should be noted that, this paper analyzes the deck structure under this moving load and calculates the effect of loading on the access bridge. Finally, maximum deflection was computed from which efficient design for the bridge can be performed (Khodadadi, 2013).

CONCLUSION

As mentioned, ports are the most important economic, political and military bottlenecks, therefore shoreline structures have crucial role in the countries' life. Pile and deck wharf and their access bridges are one of the parts which are supplier of coupling between the land and the waterfront. In this paper, dynamic load modeling for dynamic analysis of the deck is done by MATLAB program. The main output of this research is to answer the question, that the moving vehicle passing with heavy cargo, with unconventional weight can cause what reactions in the deck?

As a case study, the steps of structure analysis of a deck under passing of Bogie of 125 tons NATO classification is presented. For dynamic analysis, deck properties including mass per unit length, bending stiffness, and span length are estimated based on architectural plans.

For dynamic analysis of vehicle passing over the deck, deck properties affect the results, thus a loop of recursive solution will converge to the final design properties of the deck. After the material properties are determined damping and elasticity of the beam, that is the wharf deck, for a constant span length is only a function of the cross-sectional shape which is solved within the recursive MATLAB code. Under 125 ton trailer passing over the wharf at the maximum speed of design, bending moment and shear force are respectively 1500 KN.m and 650 KN for the 10 meters span-length deck.

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How to cite this article: (Harvard style)

Azarsina, F.; Ashrafi Khorasani, N.; Khodadadi, F., (2013). Structural analysis of the deck of access bridges in offshore docks under dynamic loading of moving heavy vehicles (Case study: 10 feet concrete deck with prefabricated beam, under the passage of 125-ton bogie). Int. J. Mar. Sci. Eng., 3 (3), 129-132.