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Dynamic Response of an Experimental Model for Offshore Platforms with Periodic Legs

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Abstract. A new class of offshore platforms with periodic legs is presented. The dynamic response of this class of platforms to wave excitation is determined theoretically and experimentally. The emphasis is placed here on studying the behavior of legs with geometric and material periodicity.

A theoretical model is developed to model the dynamics of periodic legs using the Transfer Matrix method. The predictions of the model are validated experimentally using a scaled experimental model of an offshore platform. The experimental model is tested inside a water basin which is provided with a water wave generator mechanism capable of generating periodic as well as random waves. The dynamic response of the platform with periodic legs is determined for different submergence levels. The obtained results are compared with the response when the platform is provided with plain legs. It is found that the periodic legs are capable of attenuating considerably the vibration transmitted from the water to the platform both in the axial and lateral directions over a broad frequency band. Comparisons between the experimental results and the theoretical predictions are found to be in close agreement. The developed theoretical and experimental techniques provide invaluable tools for the design of this new class of offshore platforms with periodic legs.

Keywords: Periodic beam, Dynamic response, Offshore platform.

1. Introduction

There are more than 5000 steel offshore platforms around the world. The main dynamic excitations depend on wind, sea waves, ice and earthquakes. Based on engineering experiences vibration amplitude reduces 15% the life of the structure enhanced double. Offshore platforms, such as the one shown in Fig.1, have many uses including oil exploration and production, navigation, ship loading and unloading, and to support bridges and causeways. Offshore oil production is one of the most visible of these applications and represents a significant challenge to the design engineer. These offshore structures must function safely for design lifetimes of twenty years or more and are subject to very harsh marine environments. Some important design considerations are peak loads created by hurricane wind and waves, fatigue loads generated by waves over the platform lifetime and the motion of the platform.

Fig. 1. Oil production platforms.

The offshore platform construction should provide technical information on the way in which vibration should be taken into account in the design and construction of offshore installations especially at the legs of the platform which are exposed to the sea waves. The leg design and isolation should be duly considered to avoid the effect of loads generated by the sea waves. The platforms are sometimes subjected to strong currents which create loads on the mooring system and can induce vortex shedding and vortex induced vibration.

There are many sources of vibration that affect the offshore platform structures, for example machinery, water waves, wind and impact boats.

We concentrate on the high effect of these sources, large sea waves and we try to make a good solution to providing the better isolation of mechanical vibration by using the periodic structure technique.

2. Background

The basic idea underlying the whole concept of periodic structures is that when a wave is traveling in a medium and meets a transition in that medium, a part of it will propagate and another part will be reflected. In a regular structure the wave is expected to travel without any change until it reaches the boundaries of that structure, but when the structure exhibits a change in its geometry and/or material properties, the incident waves will divide as described before. A part of the reflected wave will interact with the incident wave in a manner that will generate distractive interference. This research presents a new approach to isolate the vibration aspects of offshore platform structures, by making the platform legs as periodic structures. A periodic structure consists of an assembly of identical elements connected in a repeating array which together form a completed structure. Examples of such structures are found in many engineering applications. These include bulkheads, airplane fuselages, and apartment buildings with identical stories. Each such structure has a repeating set of stiffeners which are placed at regular intervals. The study of periodic structures has a long history. Wave propagation in periodic systems has been investigated for approximately 300 years.

When constructive interference occurs, the frequency is characterized by being the pass band of the structure; while, if they destructively interfere, the frequency is characterized by being the stop band of the structure. If the structure setup is repeated for several times, it is known as periodic structure. The destructive effects will show more significantly when the repetitions of the structure unit increase in number because as the part of the wave that propagates incorporates other similar changes in the medium, another part of it is destructed and so on.

In his paper reviewing the research performed in the area of wave propagation in periodic structures, Mead[1] defined a periodic structure as a structure that consists fundamentally of a number of identical structural components that are joined together to form a continuous structure. An illustration of a simple periodic beam is presented in Fig. 2.

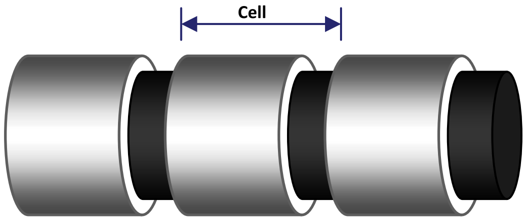


Fig. 2. An illustration of a simple periodic beam.

Ungar[2] presented a derivation of an expression that could describe the steady state vibration of an infinite beam uniformly supported on impedances. That formulation allowed for the analysis of the structures with fluid loadings easily. Later, Gupta[3] presented an analysis for periodically-supported beams that introduced the concepts of the cell and the associated transfer matrix. He presented the propagation and attenuation parameters' plots which formed the foundation for further studies of one-dimensional periodic structures. Faulkner and Hong[4] presented a study of mono-coupled periodic systems. Their study analyzed two types of mono-coupled systems are considered as numerical examples: a spring-mass oscillating system and a continuous Timoshenko beam resting on regularly spaced knife-edge supports. Their study analyzed the free vibration of the spring-mass systems as well as point-supported beams using analytical and finite element methods.

Mead and Yaman[5] presented a study for the response of one-dimensional periodic structures subject to periodic loading. Their study involved the generalization of the support condition to involve rotational and displacement springs as well as impedances. The effects of the excitation point as well as the elastic support characteristics on the pass and stop characteristics of the beam are presented. Later, Mead, White and Zhang[6] proved that the power transmission in both directions of a simply supported beam excited by a point force was equal regardless of the excitation location. These results were generalized by Langley[7] for generalized supports and excitation in the absence of damping.

Langley investigated the localization of a wave in a damped one-dimensional periodic structure using an energy approach. This method is based on vibration energy flow, and excellent agreement with exact results is demonstrated for a periodic beam system. Gry and Gontier[9] concluded the insufficiency of both Euler-Bernoulli and Timoshinko beam theories for the analysis or railway tracks. Thus, they developed a generalized cross-section displacement theory for periodic beams with general support conditions for the study of the dynamic characteristics and vibration attenuation of railways.

The most common damping technique studied in periodic structures was through the introduction of random disorder. The concept of wave localization phenomenon was introduced to the study of mechanical wave propagation by Kissel[10] through the use of the transfer matrix approach. Ariaratnam and Xie[11] studied the effect of introducing random variations of the parameters of a periodic beam on the localization parameter. Later, Cetinkaya[12], by introducing random variation in the periodicity of one dimensional bi-periodic structure, showed that the vibration can be localized near to the disturbance source. Therefore, the wave components corresponding to higher propagation zones penetrate deeper into a structure. It is observed that the right boundary of the propagation zones is the mean localization factor asymptote. Xu and Huang[13] showed that the introduction of a finite number of nearly-periodic supports into an infinite beam introduced a large band of localized vibration and reduced the amount of energy transferring through the nearly-periodic segment. Using the same concept, Ruzzene and Baz[14] used shape memory inserts into a one dimensional rod, and by activating or deactivating the inserts they introduced a periodicity which in turn localized the vibration near to the disturbance source. Later, they used a similar concept to actively localize the disturbance waves traveling in a fluid-loaded shell[15]. Thorp, Ruzzene and Baz[16] applied the same concept to rods provided with shunted periodic piezoelectric patches which again showed very promising results. Asiri, Baz and Pines[17] developed a new class of these periodic structures called passive periodic struts, which can be used to support gearbox systems on the airframes of helicopters. When designed properly, the passive periodic strut can stop the propagation of vibration from the gearbox to the airframe within critical frequency bands, consequently minimizing the effects of transmission of undesirable vibration and sound radiation to the helicopter cabin. The theory governing the operation of this class of passive periodic struts is introduced and their filtering characteristics are demonstrated experimentally as a function of their design parameters. Asiri and

Aljawi[18] presented a new class of periodic mounts for isolating the vibration transmission from vehicle engine to the car body and seats.

3. A Periodic Beam Model

3.1 Theoretical Model

Spectral finite element analysis will be used to analyze the beam vibrations and determine the propagation parameter, μ. This parameter indicates the regions for which there is attenuation of the vibrations transmitted through the structure (stop bands) and where waves are allowed to transmit energy (pass bands) This section will begin with the development of spectral finite element analysis for transverse vibrations of a beam and the effect of geometrical changes in the cell structure will be presented. For a beam (see Fig. 3). The equation of motion may be derived by considering a beam section with uniform properties.

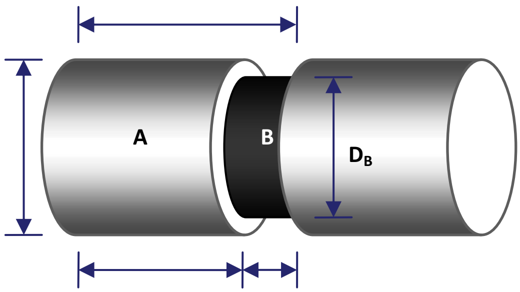


Fig. 3. Beam geometry.

$$EI\, v'''' + \rho A\, \ddot{v} = 0 \tag{1}$$

which has the solution

$$v(x,\omega) = a_1 e^{-ikx} + a_2 e^{ikx} + a_3 e^{-kx} + a_4 e^{kx} \tag{2}$$

in vector form

$$v(x,\omega) = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 \end{bmatrix} \begin{bmatrix} e^{-ikx} \\ e^{ikx} \\ e^{-kx} \\ e^{kx} \end{bmatrix} \tag{3}$$

the nodal displacements of the element are given by

$$\delta = \begin{Bmatrix} v_L \\ \theta_L \\ v_R \\ \theta_R \end{Bmatrix} \tag{4}$$

and evaluating the solution at the left and right nodes,

$$\delta = Pa \tag{5}$$

with

$$a = \{a_1 \quad a_2 \quad a_3 \quad a_4\}^T \tag{6}$$

where:

v = Lateral Displacement
θ = Rotational Displacement
F = Nodal Force
M = Nodal Moment

Applying the boundary conditions to evaluate the P gives,

At x=0,

$$v(0,\omega) = (1 \quad 1 \quad 1 \quad 1)a \tag{7}$$

$$\left.\frac{dv(x,\omega)}{dx}\right|_{x=0} = (-ik \quad ik \quad -k \quad k)a \tag{8}$$

At x=L,

$$v(L,\omega) = (e^{-ikl} \quad e^{ikl} \quad e^{-kl} \quad e^{kl})a \tag{9}$$

$$\left.\frac{dv(x,\omega)}{dx}\right|_{x=L} = (-ike^{-ikl} \quad ike^{ikl} \quad -ke^{-kl} \quad ke^{kl})a \tag{10}$$

Define P by rearranging equation (7) to (10) in matrix form, thus

$$P=\begin{bmatrix} 1 & 1 & 1 & 1 \\ -ik & ik & -k & k \\ e^{-ikL} & e^{ikL} & e^{-kL} & e^{kL} \\ -ike^{-ikL} & ike^{ikL} & -ke^{-kL} & ke^{kL} \end{bmatrix} \tag{11}$$

the nodal forces and moments must satisfy the following at the right and left ends of the beam segment (see Fig. 4).

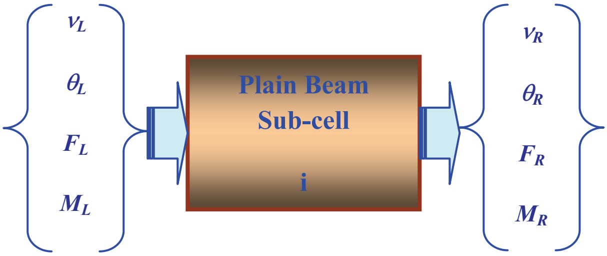


Fig. 4. The dynamics of plain beam sub-cell.

The nodal forces and moments are

$$F = \begin{Bmatrix} F_L \\ M_L \\ F_R \\ M_R \end{Bmatrix}_i = \phi a = \phi P^{-1}\delta \tag{12}$$

where ϕ is given by rearrange equation (12) to (15) in matrix form

$$\phi=EI\begin{bmatrix} ik^3 & -ik^3 & -k^3 & k^3 \\ k^2 & k^2 & -k^2 & -k^2 \\ -ik^3e^{-ikL} & ik^3e^{ikL} & k^3e^{-kL} & -k^3e^{kL} \\ -k^2e^{-ikL} & -k^2e^{ikL} & k^2e^{-kL} & k^2e^{kl} \end{bmatrix} \tag{13}$$

thus, the stiffness matrix [K] is then given by

$$[K] = \phi P^{-1} \tag{14}$$

The forces at the ends of the element are related to the displacements by the relation

$$\begin{Bmatrix} F_L \\ M_L \\ F_R \\ M_R \end{Bmatrix} = [K] \begin{Bmatrix} v_L \\ \theta_L \\ v_R \\ \theta_R \end{Bmatrix} \tag{15}$$

Where

$$[K] = \begin{bmatrix} K_{11} & K_{12} & K_{13} & K_{14} \\ K_{21} & K_{22} & K_{23} & K_{24} \\ K_{31} & K_{32} & K_{33} & K_{34} \\ K_{41} & K_{42} & K_{43} & K_{44} \end{bmatrix} = \begin{bmatrix} K_{LL} & K_{LR} \\ K_{RL} & K_{RR} \end{bmatrix} \tag{16}$$

where

$$K_{LL} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}, \qquad K_{LR} = \begin{bmatrix} K_{13} & K_{14} \\ K_{23} & K_{24} \end{bmatrix}$$

$$K_{RL} = \begin{bmatrix} K_{31} & K_{32} \\ K_{41} & K_{42} \end{bmatrix} \qquad K_{RR} = \begin{bmatrix} K_{33} & K_{34} \\ K_{43} & K_{44} \end{bmatrix}$$

When considering a series of cells, one may derive a relation between consecutive left-end of elements (i to i + 1). It is given by Fig. 5.

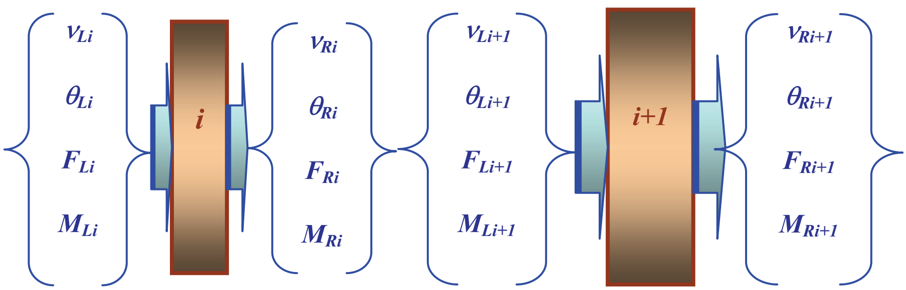


Fig. 5. Interactive between two consecutive cells.

$$\begin{Bmatrix} v_L \\ \theta_L \\ F_L \\ M_L \end{Bmatrix}_{i+1} = [T] \begin{Bmatrix} v_L \\ \theta_L \\ F_L \\ M_L \end{Bmatrix}_i \tag{17}$$

or

$$Y_{i+1} = [T_1]\, Y_i \tag{18}$$

$$\begin{Bmatrix} F_{L_i} \\ F_{R_i} \end{Bmatrix} = \begin{bmatrix} K_{LL} & K_{LR} \\ K_{RL} & K_{RR} \end{bmatrix} \begin{Bmatrix} v_{L_i} \\ v_{R_i} \end{Bmatrix} \tag{19}$$

where

$$\begin{Bmatrix} v_{L_{i+1}} \\ F_{L_{i+1}} \end{Bmatrix} = \begin{Bmatrix} v_{R_i} \\ -F_{R_i} \end{Bmatrix} \tag{20}$$

$$\begin{Bmatrix} F_{L_i} \\ -F_{L_{i+1}} \end{Bmatrix} = \begin{bmatrix} K_{LL} & K_{LR} \\ K_{RL} & K_{RR} \end{bmatrix} \begin{Bmatrix} v_{L_i} \\ v_{L_{i+1}} \end{Bmatrix} \tag{21}$$

The transfer matrix [T] may be constructed using the transformation

$$T = \begin{bmatrix} -K_{LR}^{-1}K_{LL} & K_{LR}^{-1} \\ K_{RR}K_{LR}^{-1}K_{LL} - K_{RL} & -K_{RR}K_{LR}^{-1} \end{bmatrix} \tag{22}$$

thus, the eigenproblem is formulated as

$$[T] \begin{Bmatrix} v_L \\ \theta_L \\ F_L \\ M_L \end{Bmatrix}_i = \lambda \begin{Bmatrix} v_L \\ \theta_L \\ F_L \\ M_L \end{Bmatrix}_i \tag{23}$$

combining equations (E.18) and (E.23) gives:

$$Y_{i+1} = \lambda Y_i \quad (24)$$

indicating that the eigenvalue λ of the matrix [T] is the ratio between the elements of the two state vectors at two consecutive cells.

Hence, one can reach the following conclusions:

If $|\lambda| = 1$, then $Y_{i+1}=Y_i$ and the state vector propagates along the strut. This condition defines a "Pass Band" condition.

If $|\lambda| \neq 1$, then $Y_{i+1} \neq Y_i$ and the state vector is attenuated as it propagates along the strut. This condition defines a "Stop Band" condition.

A further explanation of the physical meaning of the eigenvalue λ can be extracted by rewriting it as:

$$\lambda = e^{\mu} = e^{(\alpha + i\beta)} \quad (25)$$

where μ is the propagation factor which is a complex number whose real part (α) represents the logarithmic decay of the state vector and its imaginary part (β) defines the phase difference between the adjacent cell.

For the periodic beams, there are two propagation factors (μ), one for the lateral deflection and anther for rotational deflection.

Lateral deflection:

$$\mu_1 = \cosh^{-1}\left(\frac{t_{11} + t_{33}}{2}\right) \quad (26)$$

Rotational deflection:

$$\mu_2 = \cosh^{-1}\left(\frac{t_{22} + t_{44}}{2}\right) \quad (27)$$

where the t_{11}, t_{22}, t_{33}, and t_{44} get from the transfer matrix [T]

$$[T] = \begin{bmatrix} t_{11} & t_{12} & t_{13} & t_{14} \\ t_{21} & t_{22} & t_{23} & t_{24} \\ t_{31} & t_{32} & t_{33} & t_{34} \\ t_{41} & t_{42} & t_{43} & t_{44} \end{bmatrix} \quad (28)$$

3.2 Periodic Leg Design

In our case, we will investigate the effect of material and geometry discontinuity with asymmetric cells for vibration isolation. The propagated waves across the periodic beam cell largely depend on the extent of matching and appropriate materials. Aluminum and Mearthane Durethane material will be used (Fig. 6). Mearthane Durethane is a solid urethane elastomeric. Formulations are individually compounded and tested to meet OEM requirements for durometer, tensile strength, tear strength, elongation, coefficient of friction, abrasion resistance, compression set, compression modulus, tensile modulus, resilience, solvent resistance and color. Mearthane will custom-manufacture industrial product, wheels (Table 1).

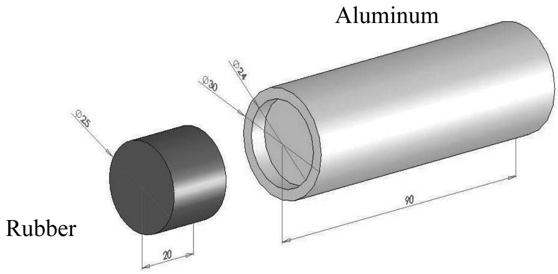


Fig. 6. An illustration of a periodic beam cell coupling.

Table 1. Experimental material property.

Material	Modules of elasticity, (N/m^2)	Density, (kg/m^3)	Wave speed (m/s)	Diameter, (m)	Length, (m)
Aluminum	70×10^{9}	2700	5128	30×10^{-3}	90×10^{-3}
Mearthane Durethane	0.000345×10^{9}	1150	17	25×10^{-3}	20×10^{-3}

Note in Fig. 7 which is obtained by MATLAB program, there are two propagation parameters associated with the beam cell. One corresponds to the near-field waves (both rightward and leftward travelling) and it has a real component for all frequencies. The other is associated with the propagating waves (leftward and rightward travelling). Also it can be seen that the first cut-off frequency is 16 Hz. In Fig. 8 the magnitudes of the response at the left end of a beam (free–free end conditions with a harmonic excitation force at the left end) composed of three, four, and five cell structures are compared. It may be seen that periodic beams composed of greater numbers of cells exhibit the attenuation regions more clearly.

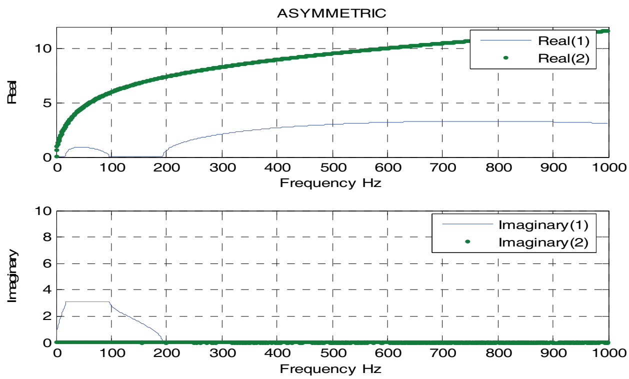


Fig. 7. Propagation parameter for a periodic beam cell.

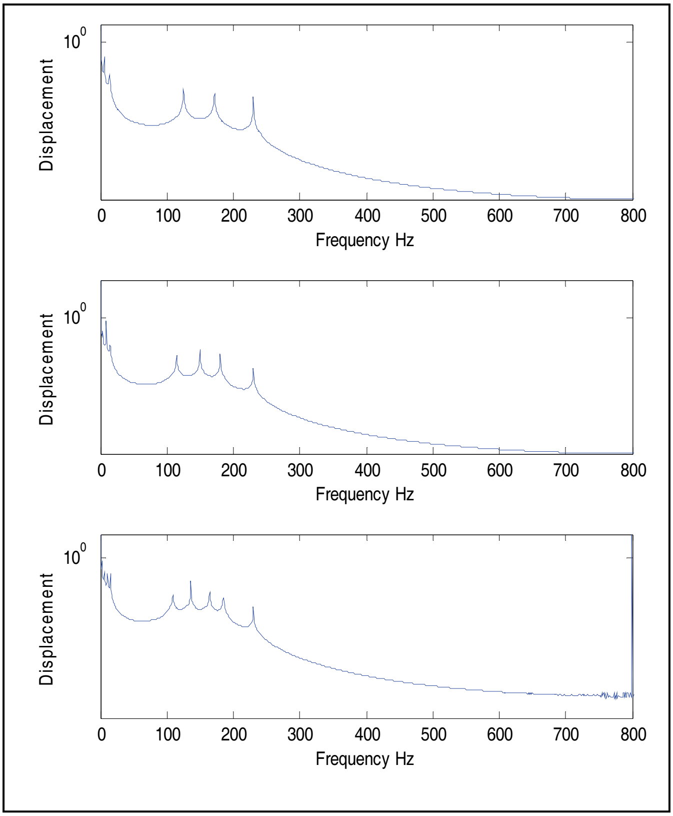


Fig. 8. Magnitude of the response for three, four, and five cells respectively.

4. Experimental Work

Periodic structures techniques were employed to act as filters of traveling waves from the sea waves to legs of the offshore platform and then to the bed of the offshore platform. The periodic beams were screwed to a 50 cm × 50 cm square plate. The vibration levels measurements are done by using the Pulse system machine. The simulation model was submerged in water in a rectangular glass tank 2m long, 1m wide and 0.5m high. The water was excited by a wave generator system at known frequencies. This experimental model is showed in (Fig. 9).

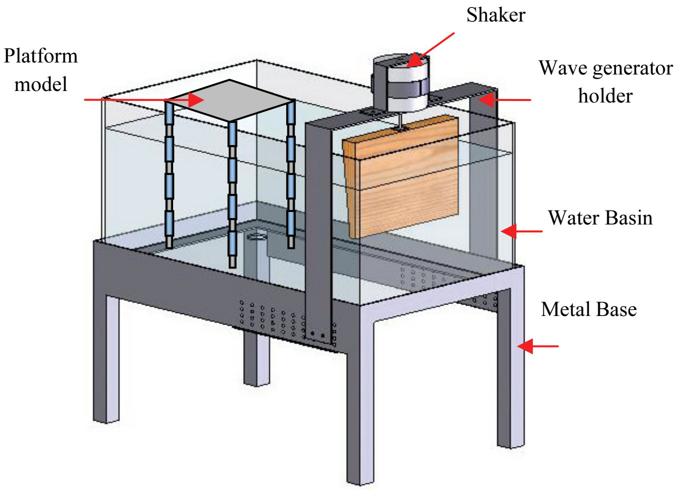


Fig. 9. The experimental test-rig.

The pulse system is a multi-analyzer system which was used to plot the frequency response functions for different configurations of periodic legs in order to develop a better understanding of the behavior of the excited periodic leg as well as developing a numerical model to study its characteristics.

The wave generator consists of a metal holder as shown in Fig. 10 and a thin plate sinking vertically into water which is connected to the vibration exciter. The main goal of using the vibration exciter in the water wave generator mechanism is to determine the input frequencies from the Pulse system by using the force transducer which is connected to the vibration exciter. The force transducer is used in mechanical-dynamics measurements together with an accelerometer to determine the dynamic forces in a structure and the resulting vibratory motions. The parameters together describe the mechanical impedance of a structure. By exciting a structure at different positions with a vibration exciter and measuring the structural response, the so-called modal analysis can be made describing the total behavior of the structure as a system.

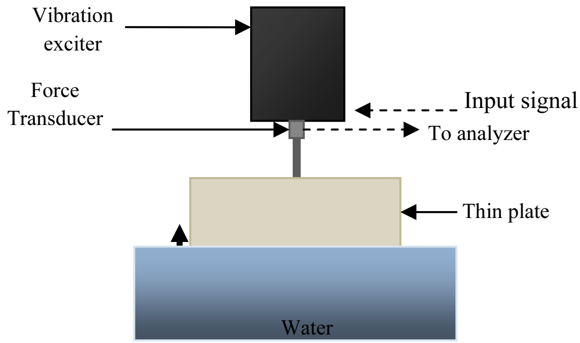


Fig. 10. An illustration of wave generator parts set-up.

4.1 Experiments on Legs Alone

In order to clearly understand the effect of the water waves on the periodic legs alone a beam is tested with water waves generator mechanism for both types (plain, and periodic) with the same conditions and dimensions. These experimental tests provide a basis for comparison of the dynamic characteristics between the plain and periodic beams.

The plain beam is made of aluminum with 500, 600, and 700 mm lengths and 30 mm diameter. They are supported vertically in the basin and submersed in water to a depth of 200 mm. Also the periodic beams with 5, 6, and 7 cells are tested at the same conditions. The lengths of the plain beams above the water level (200 mm) are 300, 400, and 500 mm. Similarly, the number of cells of the periodic beams above the water level are 3, 4 and 5. These represent the actual parameters studied and analyzed in this research. The beam is excited by water waves and the measurement was taken by an accelerometer from the free end (Fig. 11). By using the Pulse System, frequency response of each beam can obtained to make comparisons between the plain and periodic beams.

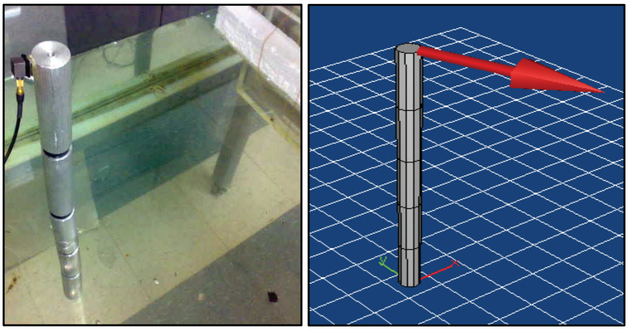


Fig. 11. Experimental set-up and the accelerometer position.

4.2 Experimental Results

Experimental results for testing the plain and periodic beams were obtained at a frequency range from 1 Hz to 1000 Hz. The main goal of these experiments is to investigate the effect of periodic beams on isolation. To provide better study of wave attenuation, comparison between both types of beams is outlined and compared with the attenuation factors which are displayed in Fig. 7. Figure 12 presents the frequency response obtained for the plain and periodic beam with 3 cells. It can be noticed that the periodic beam is more active in isolation and reduction of vibrations. Also the wave attenuation by the periodic beam is from 20 Hz to 100 Hz and from 200 Hz to 1000 Hz which is the same stop band ranges of the propagation factor. The same comments can be noticed in Fig. 13 and 14 which present the results for 4 cells and 5 cells respectively. It may be seen that periodic beams composed of greater number of cells exhibit the attenuation regions more clearly.

In the alone periodic beam experiment previously tested, the attenuation factor of the beam, as calculated numerically by the real part of the propagation factor of the periodic leg model, is plotted below the frequency response obtained experimentally for alone periodic beam for the sake of comparison. The results shown emphasize the accuracy of the periodic leg model used to predict the behavior of the proposed beam over the attenuation bands.

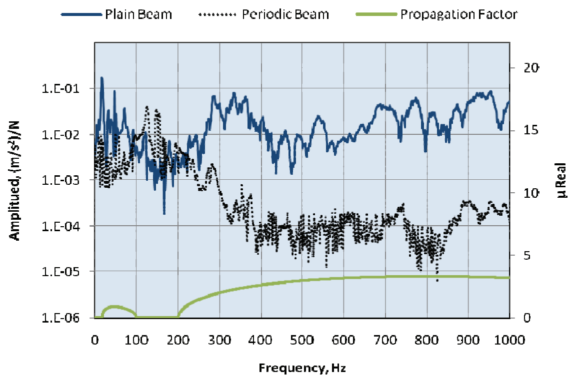


Fig. 12. The frequency response of 3 cells together with the numerical results of the stop bands for the proposed beam.

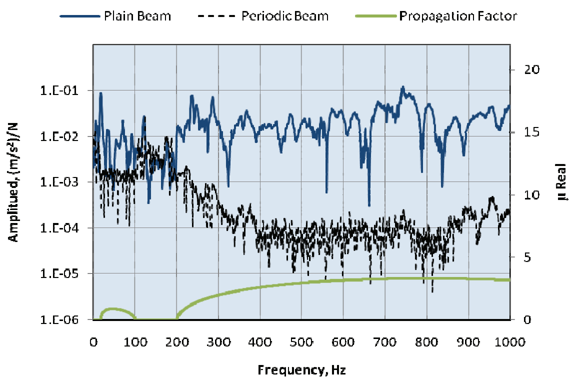


Fig. 13. The frequency response of 4 cells together with the numerical results of the stop bands for the proposed beam.

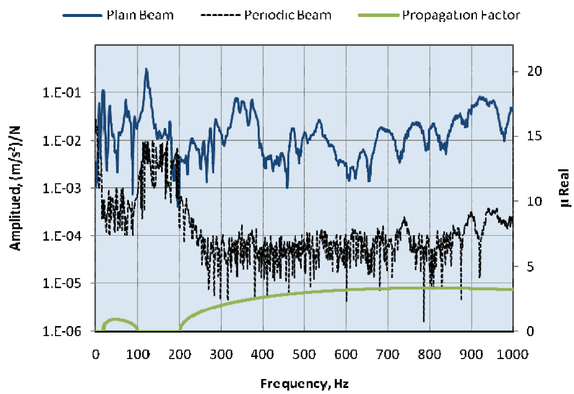


Fig. 14. The frequency response of 5 cells together with the numerical results of the stop bands for the proposed beam.

4.2.1 Effect of Water Level

In order to get a better understanding of the external effect on the offshore platform with periodic legs, the relationship between water level and the frequency response of alone periodic leg is outlined. The water level in the basin was increased to 300 mm. The alone periodic leg with 5 cells that was previously presented was tested under the new conditions and compared with the plain beam. Also two levels of water were tested to evaluate to effect on vibration isolation and attenuation factor at the same experimental testing conditions described above.

Figure 15 shows that the periodic leg is effective in reducing vibration due to water level increase. Comparison between two levels of water testing for periodic legs is presented in Fig. 16. It can be noticed that more attenuation occurs when the water level increases for frequencies greater than 300 Hz. So, the water level acts as a factor that influences vibration reduction and this will be examined further below.

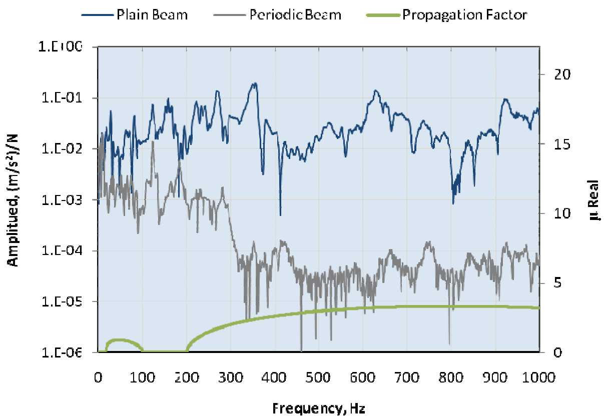


Fig. 15. The frequency response of 5 cells periodic leg with the numerical results of the stop band at water level 300mm.

4.3 Platform Experimental Model

The beams (legs) are joined with a rectangular plate. The proposed plate was 500 mm by 400 mm and 5 mm in thickness. The plate was then divided into 25 measurement points in order to define it in the Pulse System (Fig. 17). The beams are joined with the plate to simulate the platform. One model is joined with plain beams (plain legs) and another model joined with periodic beams (periodic legs) at 3, 4, and 5 cells as showing in Fig.18.

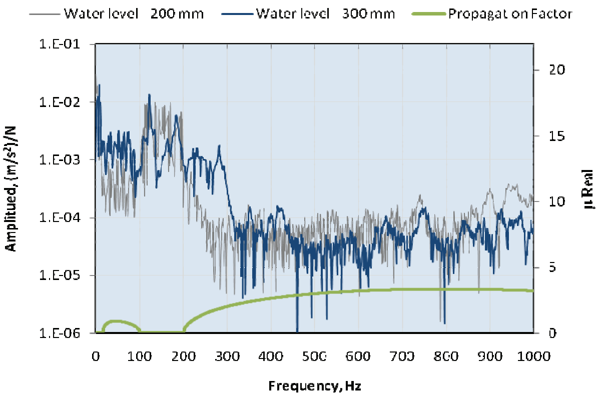


Fig. 16. The frequency response of 5 cells periodic leg with different water levels.

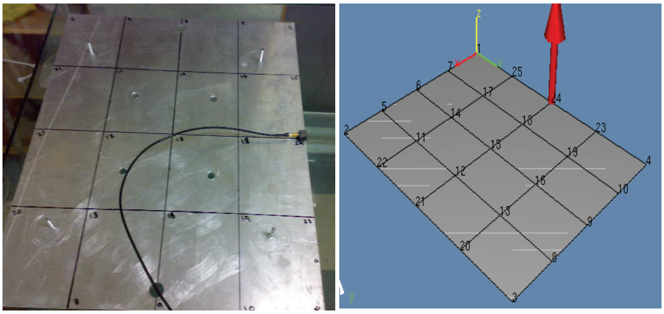
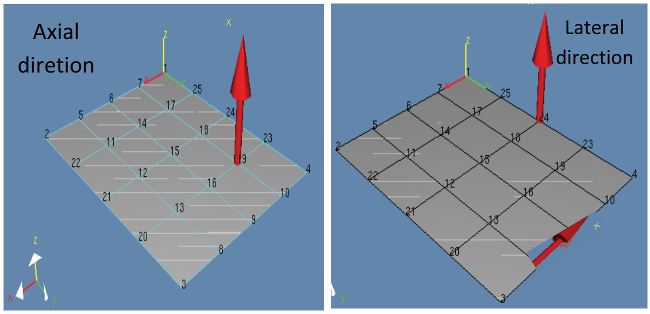


Fig. 17. Measurement points in the rectangular plate.

Fig. 18. The simulation platform model: (a) with plain legs, (b) with periodic legs.

Two measurement points were chosen for testing. One was close to the end joint of one beam (point A), and another point at the middle of the plate edge (point B). An accelerometer was connected to selected points to determine the frequency response of the simulation platform model which was excited by water waves. The accelerometer was set in axial position for both measured points and laterally for measurement point B (Fig. 19).



•measurement point A (b) measurement point B

Fig. 19. The selected measurement points.

The main objective in this experimental testing was to study the dynamic response of the simulation platform model by frequency response of measurement point of the proposed plate. Comparisons between both legs types are outlined. An accelerometer was connected to selected points to determine the frequency response of simulation platform model which was excited by water waves. The experimental set-up is illustrated in Fig. 20.

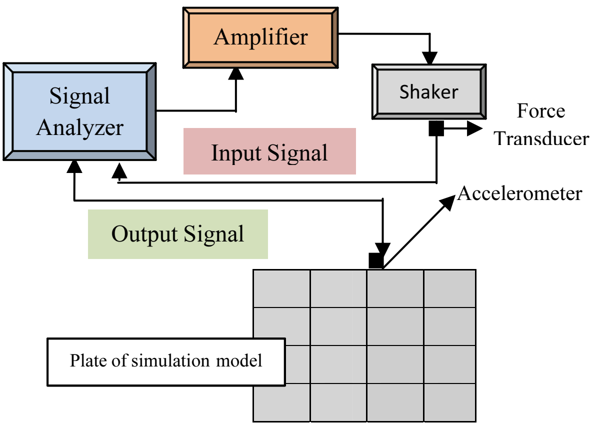


Fig. 20. Experimental set-up.

4.4 Experimental Results

Figure 21 shows the frequency response curve obtained in range 1 Hz to 1000 Hz for the simulation platform model with the 3-cell periodic beam at measurement point A in axial direction. It shows a vibration reduction for frequencies over 300 Hz.

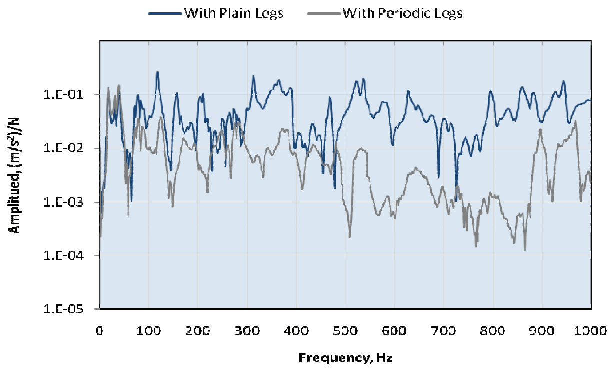


Fig. 21. The frequency response of the platform model with 3 cells periodic legs in axial direction at point A.

Figure 22 shows the frequency response curve for the simulation platform model with the 4-cell periodic beam at the same measurement point. It shows more vibration reduction. The same comments can be noticed in Fig. 23 which presents the results for simulation platform model with the 5-cell periodic beam. It shows more reduction of vibration when the number of cells is increased. The water waves propagate through the legs to the proposed plate, so the periodic legs act as a filter for wave propagation and to isolate the vibration causing reduction of vibrations.

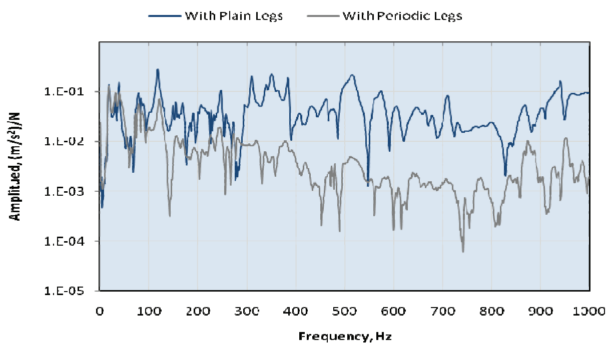


Fig. 22. The frequency response of the platform model with 4 cells periodic legs in axial direction at point A.

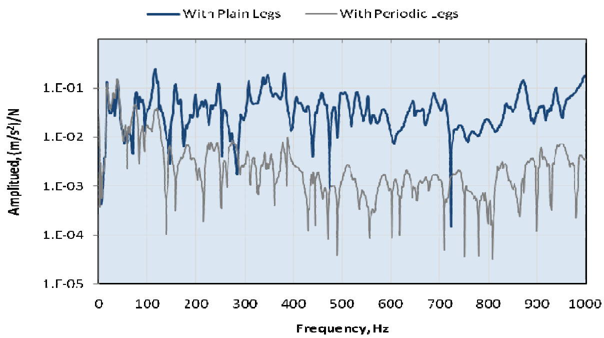


Fig. 23. The frequency response of the platform model with 5 cells periodic legs in axial direction at point A.

Experimental testing at the measured point B were obtained for the frequency response range from 1 Hz 1000 Hz. Fig. 24-26 shows the vibration reduction when the periodic legs are used. The attachment point B was at the middle of the proposed plate. The vibration level is greater than the vibration level measured at the point A because it is close to the leg.

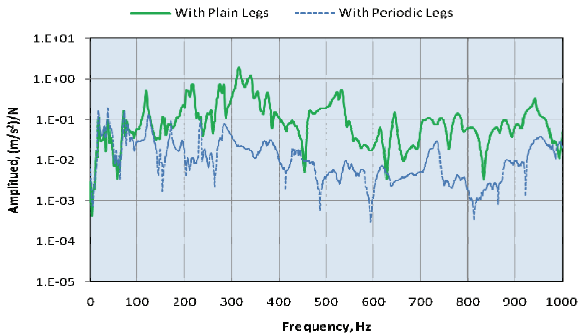


Fig. 24. The frequency response of the platform model with 3 cells periodic legs in axial direction at point B.

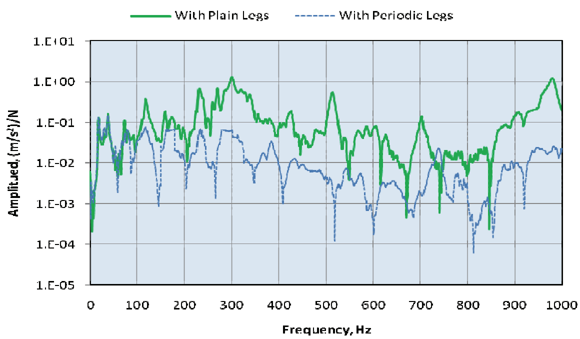


Fig. 25. The frequency response of the platform model with 4 cells periodic legs in axial direction at point B.

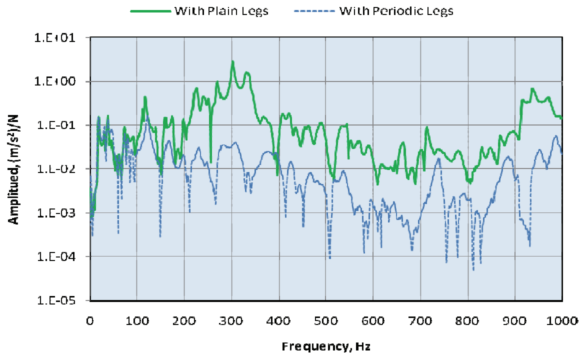


Fig. 26. The frequency response of the platform model with 5 cells periodic legs in axial direction at point B.

The testing presented the capability of periodic legs to decrease the vibration on the plate over specified frequency band displacement of plate. Also the periodicity can eliminate the localization of waves over some areas of the proposed plate. In all the results presented in this paper it is demonstrated that the periodic beam can provide attenuations over a broad frequency.

In the simulation platform model with plain legs which has been studied, the wave propagation through the legs affects to the dynamic response of the proposed plate causing the vibration localization as shown in Fig. 27. Fig. 28 proves that the second measurement point has a higher vibration localization than the first measurement point over the frequency ranges 200 to 400 Hz and 900 to 1000 Hz. Fig. 29 presents the capability of periodic legs to eliminate vibration localization at measurement point B. As previously described, increasing the cell number increases the localization elimination. So, the periodic leg with 5 cells produces more activity of localization elimination than the periodic legs with 4 or 3 cells.

4.4.1 Lateral displacement

In order to better understand the dynamic studies of the simulation platform model, an accelerometer was attached in the lateral or bending direction as shown in Fig. 30.

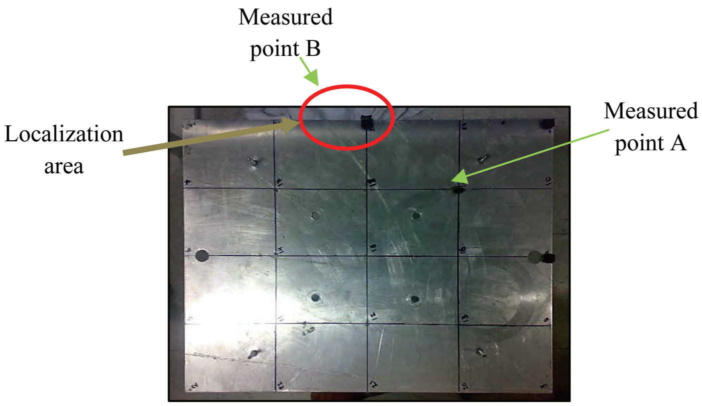


Fig. 27. Localization area in the proposed plate.

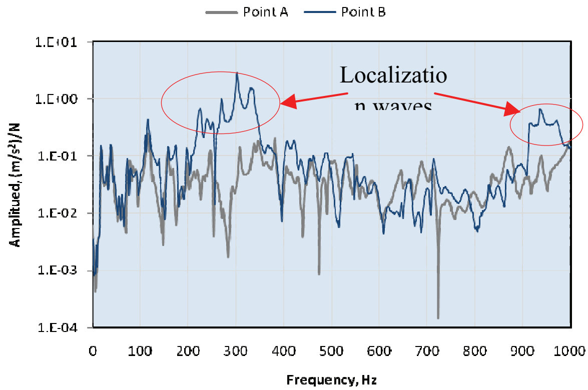


Fig. 28. Frequency response of simulation platform model with plain legs at measurement point A & B.

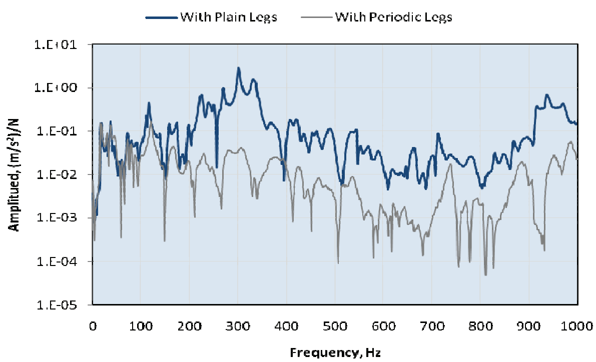
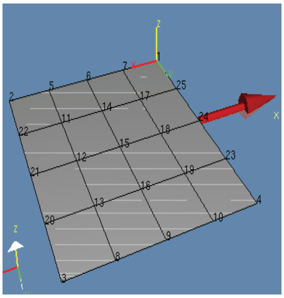


Fig. 29. Capability of periodic legs to reduce localization at point B.



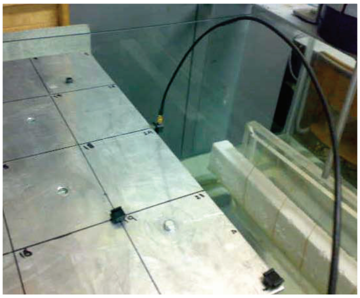


Fig. 30. Accelerometer setting in lateral direction.

In nature, water waves are normally generated by wind blowing over the water surface and continue to exist after the wind has ceased to affect them. Offshore platforms are usually located in hostile environments. These platforms undergo excessive vibrations due to water wave loads for both normal operating and extreme conditions. To ensure safety, the lateral displacements of the platforms need to be limited, whereas for the comfort of people who work at the structures, accelerations also need to be restricted. In the extreme condition, the amplitude of water waves may reach high levels caused by the lateral displacement of the offshore platform. Thus the damages may occur especially in the large sea or ocean. So, creation of the extreme wave filter may be considered. The periodic structures technique may be efficient to act as the wave filter under extreme condition.

Figures 31-33 illustrate the capability of periodic legs to act as a filters and vibration isolators for lateral displacement. Also and as previously described, a large number of cells may produce a better isolation.

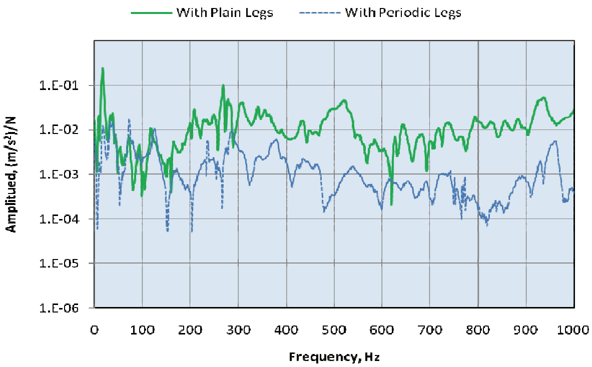


Fig. 31. The frequency response of the platform model with 3 cells periodic legs in lateral direction.

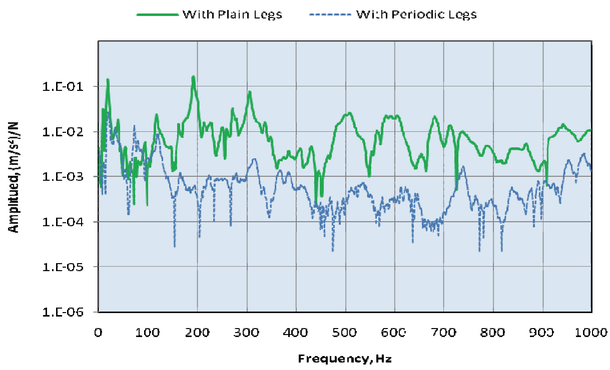


Fig. 32. The frequency response of the platform model with 4 cells periodic legs in lateral direction.

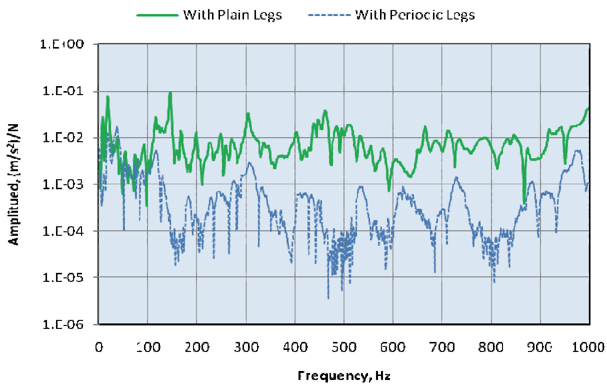


Fig. 33. The frequency response of the platform model with 5 cells periodic legs in lateral direction.

5. Conclusions and Recommendations

In this paper, the effectiveness of the periodic beam structures, with different configurations, in damping vibrations was demonstrated using various experimental and numerical models. Further, the periodic beam has shown high ability to attenuate vibrations over broad frequency bands.

The theoretical equations that govern the operation of this class of periodic beam are developed using the transfer matrix method. The basic characteristics of the transfer matrices of periodic legs are presented and related to the physics of wave propagation along these legs. The effect of the design parameters of the periodic legs on their dynamic behavior is investigated for legs with geometry and material discontinuities. The theoretical work is modeled as experimental work and it found the experimental identical with the theoretical concept.

A simulation model of offshore platform was fabricated to provide a better understanding of wave mechanics in the legs with different cells number. Two main cases of experimental testing were studied, axial direction experimental testing and lateral direction experimental testing.

The periodic legs can block the propagation of waves over specified frequency band extending in most of the considered cases between 16 to 100 Hz and 200 to 1000 Hz. The experimental model was tested at measurement points which were located at the middle of one edge. The tests were conducted with different cell numbers of periodic legs and compared with plain legs. The results showed the capability of periodic legs to decrease the vibration on the plate over a specified frequency band in axial and lateral displacements of the plate. Also the periodicity can help eliminate the localization of waves over some areas of the studied plate.

In all the results presented in this thesis, it is demonstrated that the periodic beam can provide attenuations over broad frequencies.

This paper has presented the fundamentals and basics for designing a new class of legs for offshore platforms. However, the experiments conducted here were limited to laboratory conditions on a simulation model of the offshore platform. Work is therefore needed to extend the applicability of the periodicity approach to real platforms in order to control the vibration transmission.

The offshore platform is a huge structure and there are many sources of vibration which may have an effect on it due to operation, machinery and environments factors as presented. So, the periodic structure can be employed in different cases and applications to ensure the vibration control of the offshore platforms to avoid the failures of structures, equipments, and oil piping. Thus this technique can ensure the comfortable work environments on the offshore platform. Applying periodic structures in offshore platform has opened the door for a rich field of research to study the periodic structure using possibility especially for the critical vibration problems. The periodic structures concepts can be easily implemented for the control of vibration transmission in many types of applications. And this implementation is not limited by structure size and location. But, the necessary part of this implementation is how to redesign and modify existing platform structures to take full advantage of the benefits of periodic legs.

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الاستجابة الديناميكية للنموذج التجريبي للرصيف البعيد عن الشاطئ باستخدام الأعمدة الدورية

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المستخلص. تمت دراسة نوع جديد من الأعمدة الدورية لعزل انتقال الاهتزاز من موجات مياه البحر إلى سطح الرصيف. وقد تم عرض تلك الدراسة نظرياً وعملياً لمعرفة خصائص انتقال الموجات خلالها وكيفية التحكم بها، وتمت هذه الدراسة باستخدام المادة والأبعاد بشكل دوري بطول الأعمدة.

وقد تم محاكاة الطبيعة عن طريق بناء نموذج تجريبي يحتوي على نموذج يحاكي تلك الأرصفة مغمور في حوض مائي عند مستويات مختلفة، وتتكون أمواج مياه الحوض بواسطة مكون أمواج معلوم التردد. وقد تم إجراء الدراسة التجريبية للنموذج بإستخدام المركبات الدورية ومقارنتها في حالة عدم استخدامها. تؤكد نتائج الدراسة التجريبية قدرة الأعمدة الدورية على توهين الموجات المنتقلة عبرها والقادمة من أمواج المياه. وقد تم مقارنة النتائج للدراسة التجريبية والنظرية وكان هناك توافق بينهما. وأخيرًا فقد قدمت لنا الدراسة التجريبية والنظرية التقنية المجدية والفعالة لتصميم نوع جديد من الأعمدة الدورية.