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Experimental And Numerical Investigation Of Precast Box Mold Subjected To Vibration

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Abstract
Site experiences have displayed that, the enough compression of the fresh concrete in the mold of precast concrete units depends on the tip and position of the vibrators employed for vibration. The main aim of this study is computer aided determination of the location of vibration points on the forms for the best compaction. For this goal, field experiment of mold of prefabricate concrete member has been carried out under vibration with utilizing of a dynamic strain meter. Time-dependent transverse deflection measurements were acquired at some measuring points on face of the mold of this member, for both empty and full mold conditions. Numerical analyses were carried out to obtain the displacement histories. This paper is mainly concerned with the comparison of the numerical and test outcomes of steel mold under vibration by external vibrators. The spatial integration of dynamic equations was performed to get the displacement histories using the method of finite elements. Time-history analysis was carried out by mode-superposition technique, in which load-dependent Ritz vectors were used. The results obtained by employing Ritz vectors were matched with those of Eigenvectors.
Keywords: *Prefabricated concrete element; Test measurement; External vibrator; Time-history analysis; Ritz vector analysis; Eigen vector analysis*

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I. Introduction

Despite the numerous endeavors to get another technics, vibration yet survives the dominant method in molding and compressing concrete compositions in manufacture of prefabricate concrete units. External vibrators contain an electrically or pneumatically operated motor with an out-of-balance piece. They run by vibrating the mold to which they are connected. These vibrations are transmitted to the concrete. These vibrators are mostly for prefabricate concrete study, but it is further employed in cast in place situation, particularly where there is dense reinforcement.

Frequency reach for clamp-on vibrators can be labeled at 4500, 6000, 9000 and 12000 cycles per minute. The slower a high-frequency clamp-on vibrator works, the greater is the amplitude it improves. External vibrators operating at 6000 rpm, corresponding to a frequency of 100 Hz, display a compromise, a sort of middle way in terms of technical equipment and of compaction succeeded. They can present through pattern or other medium a useful input of power in conjunction with a frequency that is wonderful proper from the viewpoint of concrete technology [1].

Location points of the external vibrators on the steel molds play a very important part in enough compression of mortar. The designer should determine position points of vibrators so that the vibration distributes nearly uniform on the mold. In practice, the abovementioned determination procedure is performed according to the designer's experiences, but mostly, it does not provide the best result, especially for the form having complicated geometry. Hence, computer aided plan of steel mold for prefabricate concrete members is necessary.

On the other hand, theoretical investigation of the dynamic behavior of an immoderate multi-degree-of freedom system under a high frequency dynamic load does not seem to have received much attention. Some researchers have displayed that the natural free-vibration mode shapes are not the best basis for a mode-superposition analysis of building exposed dynamic forces. Wilson et al. [2] have demonstrated that dynamic analyses based on a special set of -dependent Ritz vectors give more right conclusions than the using of the same number of natural mode shapes. The cause why the Ritz vectors deliver wonderful outcomes is they are produced by considering the spatial distribution of the dynamic loading, but the direct using of the natural mode shapes omits this very significant knowledge. Since the Ritz-vector algorithm is faster than the eigenvector algorithm, the former is advised for time-history analyses.

Attitude of fresh concrete in the form below vibration has not been investigated properly yet. There are limited numbers of studies in literature about the modeling of the attitude of fresh concrete below vibration. While fresh concrete is exposed vibration, researchers have observed significant changes in its rheological (yield stress, plastic viscosity) properties [3-8]. The fresh concrete under vibration loses its yield stress and behaves as a Newtonian liquid, and its plastic viscosity changes, and the concrete becomes shear thinning [9]. It is found that the yield stress of fresh concrete decreases to half of its magnitude and in some cases, became negligible, and the plastic viscosity is obtained to be unaffected by vibration [10].

The purpose of the present work is to investigate an imitation technic of attitude of mold for prefabricate concrete constructions while they are exposed external vibrators. To this end, some experimental and theoretical works have been performed. The experiments were carried out by using a displacement transducer to measure the displacement histories of some points on the face of the mold for prefabricate concrete members with the forms empty and also with the forms full of fresh concrete. First, theoretical model of the empty form is only carried out with goal of validation of the adequacy of the pattern. It is considered that with the use of this model, forming of fresh concrete exposed to vibration can be performed more exactly. The studies on the modeling of fresh concrete exposed to vibration and dynamic concrete-mold interaction analysis are over, and it is considered to be published it separately. In this paper, theoretical model is conducted employing the finite element technique (FEM). Time-history analysis is conducted by mode-superposition technic, in which load-dependent Ritz vectors are employed. The results obtained by employing Ritz vectors are matched with Eigenvectors. The adequacy of numerical pattern has been investigated by matching the outputs with test ones and found in good agreement.

II. Experiments

The experimental set-up used in the experimental study is described below.

Hardware

Related parts in articles:
a) Dynamic Strain Meter, DA-32D type (Tokyo Sokki Kenkyujo Co., Ltd.)
b) LVDT (Linear Variable Differential Transformer, Displacement Transducer)
c) ISC-16 PCI Data Acquisition Card (RC-Electronics, Inc.)

Software

SIGNALYS Program (Ziegler-Instruments GmbH, Germany, 1990)

Make-up of experiment

The experiments were realized on the face of the mold for prefabricate concrete structures. The calibration of the transducer was conducted utilizing a dial gauge which has the sensitive of 1/100 mm. Displacements obtained by the transducer were saved at the same time with 0.5 ms sample ratio for a time of 4.096 sec.

The specifications of external vibrators used in the experiments are presented in Table 1. The sketch of the mold of precast concrete unit (box member) employed in the test is seen in Fig. 1.

Table 1. Specifications of external vibrators

Mechanical Attributes					Electrical Attributes	
Vibrat. range	Centrifugal force		Weight	Max. input power	Max. current A	
Vibr./min	kg	kN	kg	W	42V	250V
6000 (200 Hz)	1157	11.34	25	1200	23	-

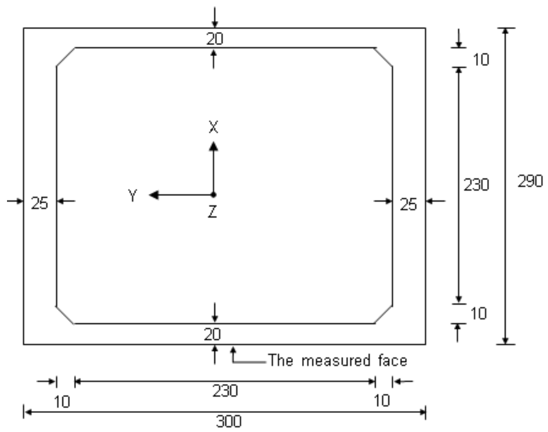

Fig. 1. Plan view of the mold for the box element (h = 97 cm)

III. Theoretical Analysis

Dynamic balance equation of a constructive tract, patterned by finite elements and lumped masses, can be stated dependent on node displacements as

$$\mathbf{M}\,\ddot{\mathbf{u}}(t) + \mathbf{C}\,\dot{\mathbf{u}}(t) + \mathbf{K}\,\mathbf{u}(t) = \mathbf{r}(s,t) \qquad (1)$$

In Eq. (1), **M**, **C** and **K** are given N×N mass, damping and rigidity matrices separately, where N is the number of degrees of freedom of the system. The time-dependent vectors $\ddot{\mathbf{u}}$, $\dot{\mathbf{u}}$ and **u** are the joint accelerations, velocities and displacements separately, **r** is the enforced force and dot indicates differentiation with respect to time.

The standard mode-superposition technique of reaction analysis is employed to resolve the dynamic balance equations of movement for the whole construction. The Modes employed in the analysis can be un-damped free-vibration modes (eigenvectors) or force-dependent Ritz-vector modes of the network differently.

The force enforced by the external vibrator to form

For most forces in Eq. 1, optional time-changing force can be more factors into a sum of space vectors multiplied by time functions:

$$\mathbf{r}(s,t) = \sum_j \mathbf{f}_j(s)\, g_j(t) = \mathbf{f}(s)\, g(t) \qquad (2)$$

The arbitrary loading in Eq. 2 is going to be compatible if construction is excited by external vibrators and can be defined as

$$\mathbf{r}(s,t) = \mathbf{f}_o \sin(\omega t) \qquad (3)$$

$$\omega = 2\pi f \qquad (3a)$$

$$T = 2\pi/\omega \qquad (3b)$$

In which $\mathbf{f}_o$, ω and f is fixed centrifugal load (the amplitude of the force), angular and cyclic frequency (100Hz) of the vibrator respectively, sin(ωt) is the function of time, and T(sec.) is period. It should be noted that, the load applied by the vibrator is vertical to surface of formwork.

The external vibrators are attached a rigid steel sheet having sizes of 20×25cm which is fixed on the surface of the form. Uniform pressure loads of shell elements located at this area is obtained by dividing the centrifugal force of the vibrator into this area.

Patterning of empty mold

Formwork is produced of steel plate 5 mm in thick. Steel sections in varied dimension and section are attached to the mold as horizontal, vertical and diagonal to power of network. Strengthening steel sections placed base of the formwork are accepted to be simply supported in pattern. The bound requirements of the form for box element are yielded in Table 2.

Table 2. The bound requirements of form

The coordinates of nodes where **u** = 0 (X-Y plane, Z = 0)			
Box element			
X (cm)	Y (cm)		
-75	-150		
-5	-150		
75	-150		
-75	-125		
-5	-125		
75	-125		
145	-80		
145	0		
145	80		
125	-80		
125	0		
125	80		
75	150		
-5	150		
-75	150		
75	125		
-5	125		
-75	125		
-145	80		
-145	0		
-145	-80		
-125	80		

-125	0		
-125	-80		

Shell finite elements are created nearly in dimensions of 10x10cm as quadrilateral, determined by the four joints as square, rectangle or trapeze elements; and triangular, stated by three joints, as transition aimed triangular elements depending on the form's geometry. Frame elements are associated with the shell elements by stating them on identical nodes.

It is accepted that the movement of the form begins from the rest, and then the initial conditions for the form are

$(\mathbf{u})_{t=0} = 0, \qquad (\partial \mathbf{u}/\partial t)_{t=0} = 0$ (4)

Eq. (1) can be solved for **u**, exposed to bound requirements (Table 1) and initial requirements (Eq. (4)). The numerical solution of Eq. (1) is made employing structural analysis and design software called SAP2000 [11].

As mentioned previously, the dynamic analysis is carried out only while form empty in order to confirm credibility of the finite element network employed in pattern and techniques employed in analyses.

IV. Exercises

In this section, some experimental and theoretical analysis results are presented. In the theoretical analyses, damping ratio is selected as %5 for all modes. Number of modes considered in the analyses is determined so that cumulative sum of modal participating mass ratios in the global X, Y and Z directions exceed %90. The time step, number of time steps and time span over which the analyses are carried out have been chosen as 0.5 ms, 8192 and 4.096 sec. separately, which were identical as in experimental registers. In all figures of exercises, positive directions for displacement histories are from the surface towards inside of the form.

The two and three-dimensional view of box member are displayed in Fig. 2, 4. The material features of steel form are below. Young's Modulus, E=199948 N/mm^2; specific weight, γ=7.682x10^{-5} N/mm^3; Poisson's ratio, ν=0.3.

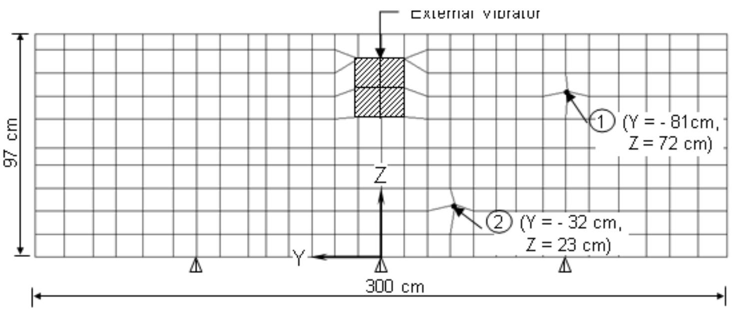

Fig. 2. The view of measured face for box element (Y-Z Plane @ X = -145 cm)

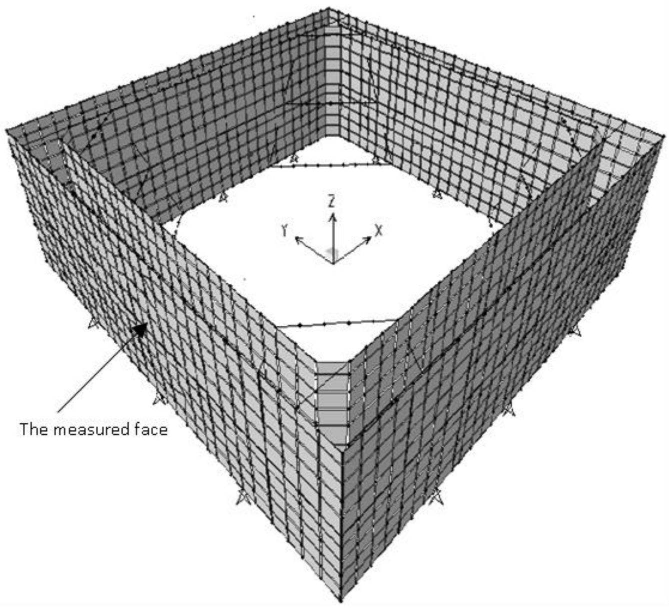

Fig. 3. Three-dimensional view of finite element network of the form for box element

Exercise 1

Free vibration analyses of the form systems for the box element are fulfilled. The cyclic frequencies of the first six un-damped free vibration modes are shown in Table 3. As seen in the Table 3, the most effective frequencies of the systems are far away from the cyclic frequency of the vibrators used in the experiments. Hence, the resonance state did not occur in the system during experiments.

Table 3. Cyclic free-vibration frequencies of the form system.

Modes	**Box** Frequency (Hz)	
1	31.64	
2	41.90	
3	41.99	
4	45.65	
5	49.00	
6	50.89	

Exercise 2

In this application, the form system for box element is taken into consideration. Eigenvalue and Ritz Vector analyses of the systems are performed using various numbers of eigenvectors and Ritz vectors alternatively. The modal participating mass ratios obtained from the various types of analyses are compared in Table 4. As seen in the tables, the Ritz vector analysis gives more sufficient results in comparison to the eigenvalue analysis.

Table 4. Modal participating mass ratios of the box element

Number of Modes	Vector Type	Cumulative sum of modal participating mass ratios in direction, (%)		
		X	Y	Z
50	Eigenvectors	27.81	28.94	0.01
	Ritz vectors	***92.53***	***93.48***	***98.84***
100	Eigenvectors	35.01	31.44	0.02
	Ritz vectors	***98.30***	***98.08***	***99.63***
150	Eigenvectors	52.35	50.66	0.18
	Ritz vectors	***99.37***	***99.29***	***99.84***
250	Eigenvectors	59.84	59.89	5.50
	Ritz vectors	***99.81***	***99.82***	***99.95***
500	Eigenvectors	69.42	73.74	86.95
	Ritz vectors	***≅100***	***≅100***	***≅100***
650	Eigenvectors	80.68	81.09	92.86
	Ritz vectors	***≅100***	***≅100***	***≅100***

Exercise 3

Test values obtained on form for **box element**, both as empty and full of fresh concrete, by using a 100 Hz. external vibrator, which was clamped-on, the surface of the form where measurements were taken at two points named 1 and 2 (see, Fig. 2). A typical part of the experimental results are compared with each other in Figs. 4 and 5.

The time-history analysis of the empty form is established employing eighty Ritz modes. In analysis, as starting Ritz vectors, Load1 (pressure load of vibrator) and acceleration loads (UX, UY, UZ) are used in the global X, Y and Z directions. Displacement histories are in the direction normal to the surface of the form. The experimental and numerical results are compared in Figs.9 and 10. Units used in the analysis are in terms of Newton (N) as force, millimeter (mm) as length and second (sec.) as time. In figures, matches are displayed in constant state pieces of attitude. Though some irregularities in attitude are displayed in earlier period space, it vanishes in a very short time and does not affect the whole behavior of the system.
In the analysis, some parameters found are given in Table 5.

Table 5. Some vibration parameters of the box element

Number of mass degrees of freedom	Modal participating mass ratios		
7353	UX	UY	UZ
	97.14	*97.10*	*99.42*

From the results in the table and in the figures, it can be seen that, taking into account only eighty Ritz modes in the analysis are sufficient to obtain the correct behavior of the empty form system.

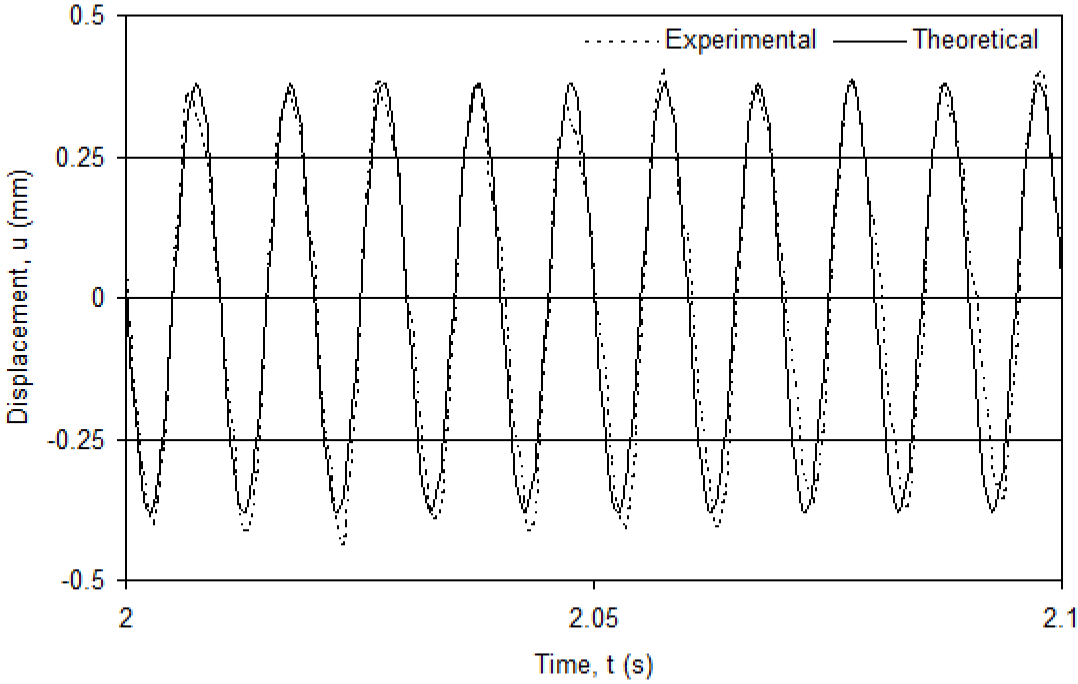

Fig. 4. Experimental and theoretical displacement histories of the empty form (Point 1)

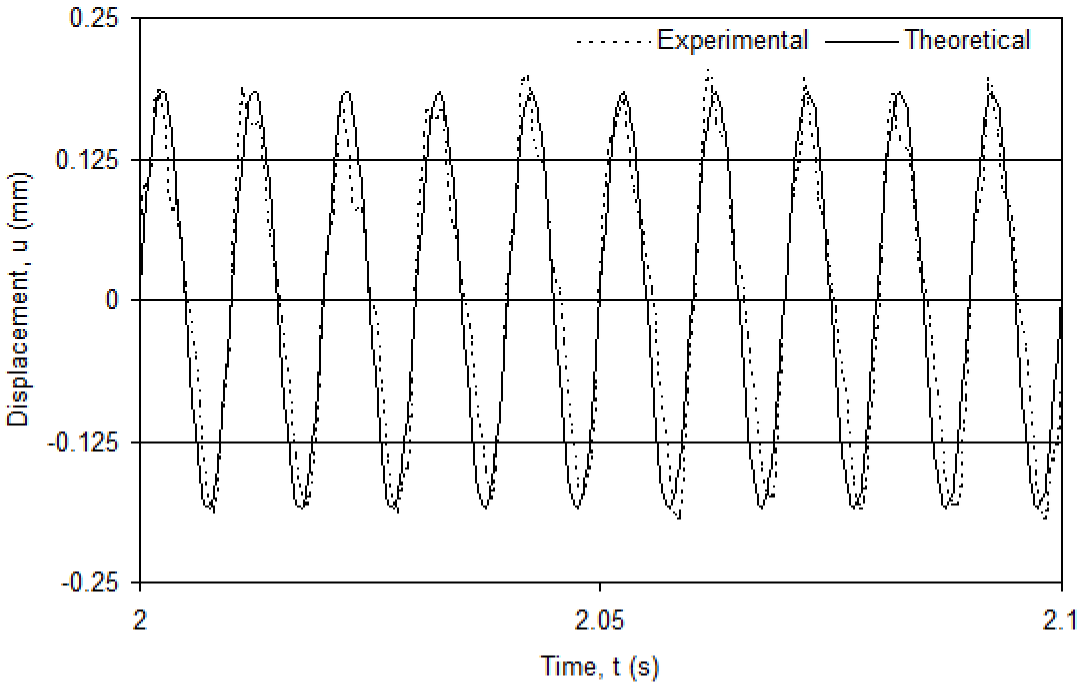

Fig. 5. Test and theoretical displacement histories of the empty form (Point 2)

V. Results And Discussion

Area test was made on prefabricate concrete structures. Displacement histories were taken on face of form for this member, both as form empty and full of fresh concrete. As shown in test outputs displayed above, displacement peak values of empty form differ quietly from full forms. On the other hand, the amplitudes decrease considerably with the distances from the vibration points. It is also seen a variation along the height of the form. From these observations, the importance of the locations of vibration points and the number of vibrator used for vibration are arisen. Moreover, the differences of test results for empty and full form establish that the fresh concrete-form interaction has to be taken into consideration in form design.

In this study, the computational results is obtained only for empty form and matched with test result. Matches indicate that, test and numerical outputs are in consistent.

In theoretical analyses, the use of Ritz vectors in any number of modes not only reduces computing time significantly but also provides the greater participating mass ratios when compared to eigenvectors, provided that the same number of modes is used. Hence, for the complex structural systems, which have the mass degrees of freedom of several thousands, it is recommended to be used Ritz vectors in mode superposition method of dynamic analysis.

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