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STRESS EVALUATION OF PUMPING STATION BUILDING SUBJECTED TO MOTOR VIBRATION

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There are many large scale pumping stations in Egypt operating under different conditions and serving irrigation and drainage operation. These pumping stations are subjected to mechanical and hydraulic problems generating dynamic loads, vibrations, and stresses affecting the structure. Safe working of these stations verifies the operation function and efficient water management and distribution. Failure and damage occur for these pumping stations lead to maintenance problems, environmental problems, and water management problems, or they can lead to rising of the water levels which may cause failure to the embankment of the canals and drains. This research was performed to estimate the effect vibrations of typical axial pumping station exposed to motor vibration. This effect should be considered in the design process or in the assessment of such structures. Dynamic tests were done using the ambient vibration technique during the operation of the motors. Eight accelerometers were used to measure the vibrations of the building. Finite element numerical model was developed for the building. Three concrete core specimens were taken from the structural elements of the building and exposed to compression tests to adjust the properties of concrete in the FE model. The natural frequencies were evaluated using the power spectra method for the measured data, and modal analysis for the numerical model. The numerical model was subjected to the real recorded signals (displacement response).

The increase in the stress due to the vibrations was calculated and compared to the designed stress capacity of the structure specified by the Egyptian code for loads. Also, the upper limits of vibrations of the building were compared to the available standards. The analysis of the collected data, the experimental results, and the results of the numerical analysis are presented.

KEYWORDS: *Dynamic analysis, vibration analysis, pump station*

1. INTRODUCTION

There are more than 1500 large-scale irrigation and drainage pumping stations in Egypt operating under different conditions. These stations are serving irrigation and drainage operations. These stations must work in a good condition away from sudden faults and breakdown under controlled environmental impacts**.**

Experience dealing with vibration of pumps shows that the most common problems are due to wrong installation and operation resulting in excessive vibration levels on the motor and the pump impellers (Smith, etal [1]). Vibration analysis of large capacity pumps suggested that greater care is required in designing the foundation supports and its proper fixing be ensured (Awasthi, et al [2]). Sugiyama, et al [3] performed vibration analysis for pump station using dynamic tests and FE model to investigate the frequencies and the vibration limits. A. Rahmann, et al [4] performed dynamic tests for pump motors to investigate the problems leads to the increase of vibrations.

Most vibration problems can be classified into: structural fracture caused by fatigue, and dynamic overload. The effect of these vibrations on the structural elements is usually neglected or under estimated during the design or the assessment of such structures. This research takes into consideration the internal forces induced in the structural elements due to dynamic loads (vibrations) to be considered during the design or the assessment of pumping station building.

This research was performed on a typical pumping station called El-Shabab-1 in New Salehia in Egypt. Figure 1, shows photos for pumping station building from inside and outside. This station contains six axial pumps working under normal conditions. The motors of the pumps are fixed upon the slab of the ground floor ceiling.

a) Motors inside the pumping station building

b) Pumping station building from outside

Fig. 1 Pumping station building.

This station as most of similar structures is exposed to bad environmental condition such as polluted water, moisture, drying and wetting cycles,...etc.

2. PROCEDURS OF TESTING

Eight accelerometers were attached to the motor, the bearing slab under the motor and the columns of the R.C frames at the level of the slab of the ground floor ceiling and at 3m higher than the slab level as shown in Fig 2. The accelerometers transfer these signals to a data acquisition system (shown in Fig. 3). This system controls the measuring process and converts the analog signals to digital ones. Also, the data is stored on a laptop computer for further analysis. The direction which was considered in the analysis is the direction parallel to the water flow direction.

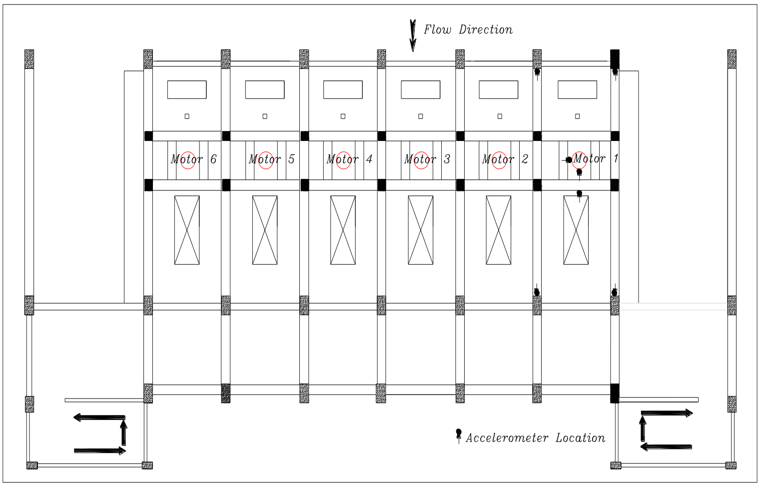


Fig. 2 Locations of the Accelerometers

Fig. 3 Data acquisition system used to collect the dynamic test data

2.1 ANALYSIS OF THE DATA

The collected data were processed and filtered for each record. The power spectral method was used for frequencies determination.

The records were collected from all channels. One of them is presented in Fig. (4) for channel #3 which is connected to accelerometers located on the concrete slab in nearest position to the motor. The acceleration time histories were exposed to double integration mathematical process to obtain the displacement responses.

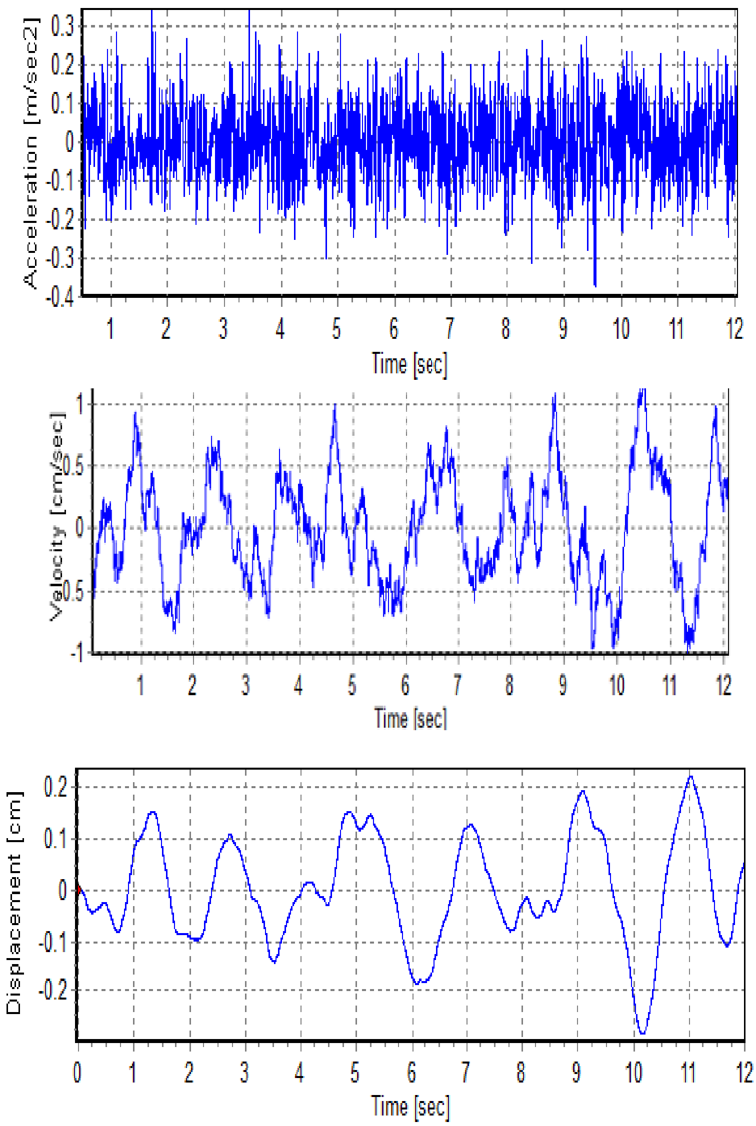


Fig. 4 Acceleration, Velocity, and Displacement Time History

The records were averaged for each channel. The powered spectra curves are constructed for each channel. Figure 5 and Fig. 6 show the powered spectra curves for the accelerometers attached to the building and the motor, respectively. Using the power spectral magnitude, the natural frequencies can be determined. The frequencies in these figures are plotted on a logarithmic scale.

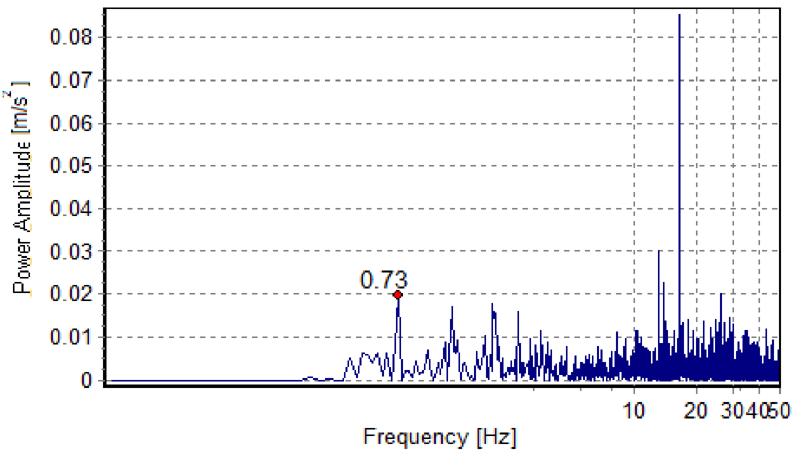


Fig. 5 Average Power Spectra of the Building

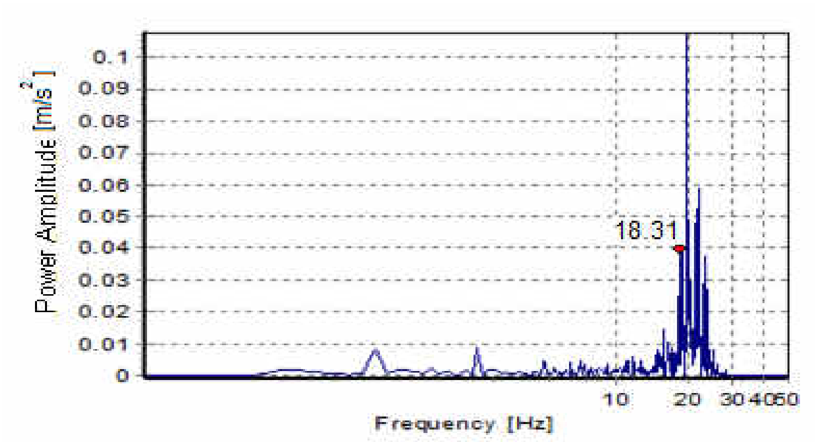


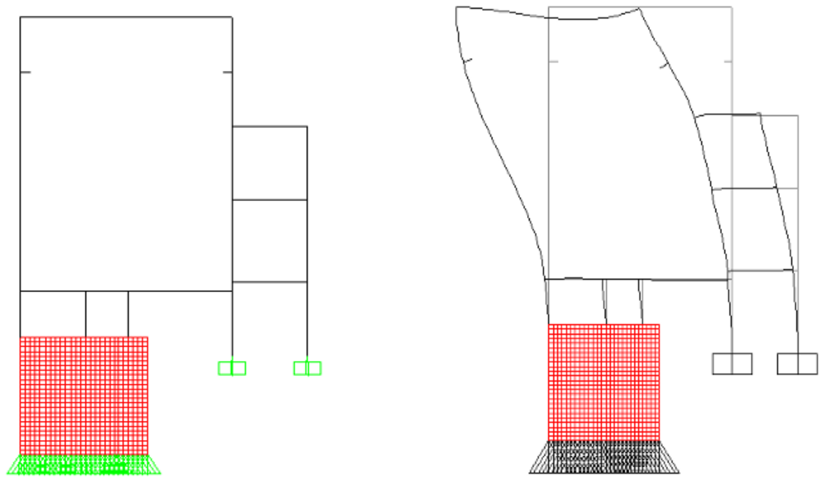
Fig. 6 Average Power Spectra of the motor

The frequency of the motors specified by the motor manufacturer was 985 rev./min (17 Hz) which was close to that obtained from measurements as shown in Fig. 6 (frequency of the first peak=18.31Hz) considering that the motor is attached to the concrete slab.

3. FINITE ELEMENT MODEL

Numerical finite element model was developed for pumping station building using Sap 2000 Program as shown in Fig. 7(a). The beams and the columns were modeled using frame elements where the pier was modeled using shell elements. The supports were modeled as hinged supports. The masses were calculated from the own weights of the actual cross section of the elements and the live load including the motors and equipments weight.

The model was exposed to the measured records (displacement response) at the motor location which was considered as the excitation of the of the dynamic load. Non-linear dynamic analyses were performed to obtain the internal forces induced in the structural elements of the building. Figure 7(b) shows the FE model and the first mode shape of the building with frequency = 0.79 Hz.



(a) (b)

Fig. 7 Finite Element numerical model and 1st mode shape

To adjust the material properties in FE model, three concrete core compression test specimens were taken from beams and columns of the building as shown in Fig. 8. The results of the compression tests are shown in table 1. The average result for the concrete strength was about 99.7 Kg/cm^2.

Table 1: Compression Test Results

Element	Strength [Kg/cm^2]
Beam	110
Beam	90
Column	99
Average	99.7

The stress and the internal forces obtained from the numerical analysis are presented in section 4.

Fig. 8 Compression test specimens taken from structural elements.

3.1 Calibration of the FE model

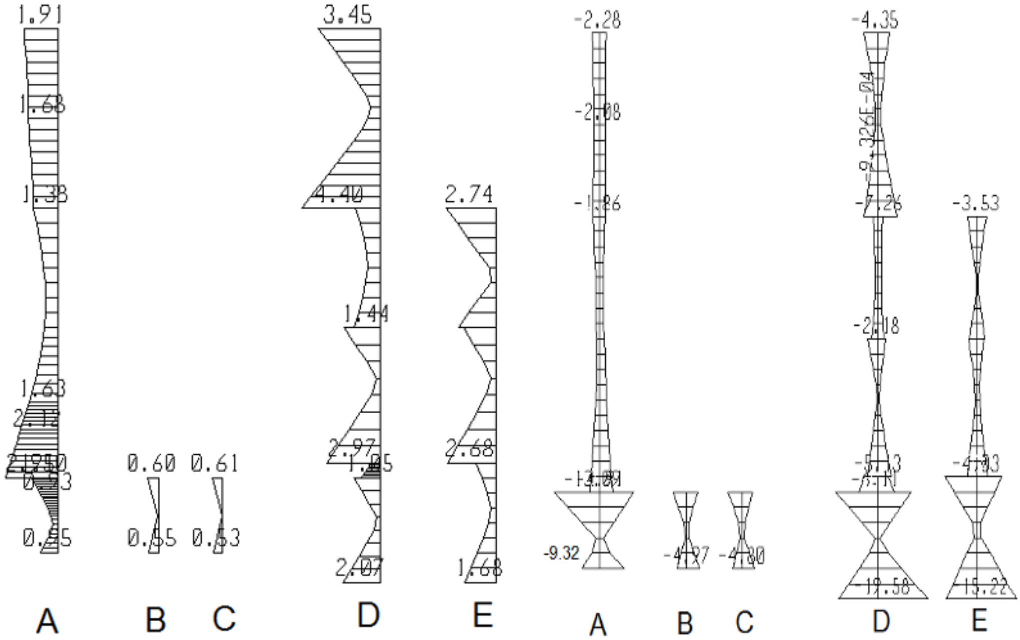
To calibrate the FE model, the frequency of the first mode shape was obtained from the model. It was 0.79 Hz which is close to the first frequency (0.73 Hz) obtained from the power spectral of the building shown in Fig. 5. Also, the maximum displacement obtained from double integration of the measured acceleration response for the first story (at the location of the accelerometer attached to the external column) was 2.65mm which matches with that obtained from the FE model (2.77mm).

3.2 Dynamic load due to earthquakes

Most of engineers design such structure to resist the seismic loads specified by codes and neglect the dynamic loads due to the vibration of the motors. To investigate the differences between the effect of these two dynamic loads, the seismic loads specified by the Egyptian code for loads [5] were calculated. These loads were used to calculate the internal forces in the structural elements required for seismic design. Response spectrum dynamic analysis method was used to perform the seismic analysis. The ground acceleration used for the analysis of this structure was 0.02g (where; g is the gravitational acceleration) when calculated according to the Egyptian code for seismic loads [5] regarding that this code deals with ordinary structures and does not include such type of structures.

4. RESULTS

Figure 9 shows the envelope of the maximum bending moment diagrams induced in column: A, B, C, D, and E obtained from seismic analysis and from the measured response of vibrations.



(a) (b)

Fig. 9 Max. bending moment in columns obtained from: a) seismic load,and b) vibration

To estimate the vibration loads, a concentrated load=36.53t, which is equivalent to about 4 times the motor weight (without the weight of the pipes and other accessories attached to the motor), was applied at the motor location. The results of the Maximum moments induced in the columns of the building (at section above the support) obtained from the seismic load case, vibration, and the concentrated load are shown in Table 2.

Table 9 Maximum moments induced in the columns [m.t]

Column	Seismic load	Vibration	Concentrated load
A	0.95	9.32	9.31
B	0.55	4.97	4.93
C	0.53	4.80	4.76
D	2.07	19.58	19.81
E	1.68	15.22	15.22
Average	1.16	10.78	10.81

By comparing the moments obtained from the two cases, it was found that the average moments obtained from the vibration case were higher than that obtained from the case of seismic design by about 9.3 times. This means that the seismic design according to [5] is not enough to take the effect of vibrations into consideration.

Also, it was found that moments obtained from a horizontal load about 4 times the motor weight acting at the motor location were approximately equal to the moments obtained from the vibrations at column fixations.

The maximum velocity obtained from measurements was about 10mm/s at the building in the nearest location to the motor which is considered safe vibrations according to the Egyptian standards [6]. The maximum stress induced in the columns calculated due to dead loads, live loads, and vibration was 89.82 Kg/cm^2. This stress level was high compared to the strength of concrete obtained from the compression test results (average strength=99.7 Kg/cm^2) which means that the factor of safety is small (equals to 1.11).

In this pump station building, the motors were rested on the ground story ceiling which causes higher vibration effect than the case of motors rested directly on foundations or ground level.

5. CONCLUSIONS

1. The natural frequencies are almost the same for FE model and the measured response. This means that the dynamic testing using the ambient vibration technique is suitable and reliable for such types of structures.
2. Vibrations cause high internal forces induced in the structural elements for such type of pumping station building where the motors are fixed on the slab of the ground story ceiling.
3. Earthquake resistant design according to the Egyptian code is not adequate to take the effect of vibrations into consideration.
4. The effect of vibration on the internal forces was approximately equivalent to a horizontal load about 4 times the motor weight (without the weight of the pipes and other accessories attached to the motor) acting at the motor location.
5. The maximum velocity obtained from measurements was safe according to the Egyptian standards but the stress level due to vibrations was high considering that the motors were rested on the ground story ceiling which causes higher vibration effect than that rested directly on foundations or ground level.
6. It is recommended to make base isolation for the motors to reduce the vibration of the structure which leads to the conservation of structure.

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قدير الإجهادات لمبنى محطة طلمبات معرض لإهتزاز المحركات

د. ياسر عبد العزيز الحاكم

أستاذ مساعد بمعهد بحوث الإنشاءات – المركز القومي لبحوث المياه

توجد العديد من محطات الطلمبات الكبيرة تخدم عمليات الرى والصرف فى مصر وهذه المحطات توجد فى ظروف تشغيل مختلفة وتتعرض لمشاكل ديناميكية وهيدروليكية تولد احمال ديناميكية واهتزازات تتسبب فى حدوث اجهادات تؤثر على هذه المنشآت والتشغيل الآمن لهذه المحطات يضمن الآداء الوظيفى الجيد لها وكفاءة ادارة وتوزيع المياه. كما ان حدوث انهيارات او خسائر فى هذه المنشآت يؤدى لمشاكل عديدة منها ارتفاع منسوب المياه فى الترع والمصارف والذى قد يؤدى الى انهيار جسورها.

وقد تم اجراء هذا البحث لتقدير تأثير الاهتزازات على محطة طلمبات تقليدية معرضة لاهتزاز المحركات داخل المحطة. حيث ان هذه الاهتزازات تتسبب فى حدوث اجهادات يجب اخذها فى الاعتبار عند تصميم او تقييم هذه المنشآت. تم عمل اختبارات وقياسات ديناميكية لقياس الاهتزاز باستخدام مجسات لتسجيل العجلة مع الزمن و تم عمل نموذج رياضى لمبنى المحطة باستخدام طريقة العناصر المحددة ثم تم اخذ 3 اكوار خرسانية من الاعضاء الانشائية للمحطة لاجراء اختبارات الضغط لهم لمعرفة مقاومتهم وضبط خواص الخرسانة بالنموذج الرياضى لمبنى المحطة.

تم حساب الترددات الطبيعية للمنشأ من تحليل نتائج الاختبارات الديناميكية كما تم استنتاجها من النموذج الرياضى باستخدام طريقة التحليل المودى. ثم تم ادخال الازاحات الحقيقية المستنتجة من القياسات الديناميكية للاهتزازات كاحمال مع الزمن على المنشأ وتم حساب الاجهادات المتولدة فى العناصر الانشائية لمبنى المحطة نتيجة هذه الاهتزازات.

تمت مقارنة الاجهادات الناتجة عن الاهتزازات بالاجهادات الناتجة عن الاحمال التصميمية المنصوص بكود الاحمال المصرى. كما تمت مقارنة الحدود القصوى للاهتزازات المقاسة بالحدود المنصوص عليها فى المواصفات المتاحة وتمت ايضا مقارنة نتائج النموذج الرياضى بنتائج الاختبارات الديناميكية.