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Peculiarities of design model formation at dynamic analysis of equipment

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1. Introduction

Design model formation is a compromise choice between the reality, excessive details and the required minimum, which makes possible to describe the real structure with maximum accuracy. When forming the design model of any structure it is impossible to consider all the available peculiarities including non-uniformity of the material properties, deviation from the perfect shape and so on. It is unnecessary to work out the models, which describe all the characteristics of the structure. Such model will be intricate and complicated with extra details, which make the assessment of the obtained results difficult.

To perform Strength Analysis of the equipment at dynamic external impacts (seismic, explosion pressure wave and so on), three main analysis methods are used: static, linear-spectral and dynamic analysis method. Hereinafter, the seismic impacts will be mainly reviewed in this paper.

2. Analysis methods and procedure

Let us review the requirements set up to the design models as for main methods of strength assessment at seismic impacts.

The main initial characteristic of a seismic impact is three-component accelerogram of the earthquake – temporary vector-function of ground seismic accelerations in two inter-perpendicular horizontal and one vertical direction. Acceleration may be expressed in m/s^2 or in fractions of gravitaty acceleration g=9.81 m/s^2.

Static method of seismic stability analysis is a simplified method according to which the distribution of seismic loads impacting on the structure is accepted like a distribution of mass and values of these loads are determined using the rated factors.

Linear-spectral method of seismic strength analysis (LSM) is a method, when seismic load values are determined based on response spectra which depends on frequency and shapes of the structure natural variations.

This method is based on the analysis of the system of differential equations of motion at natural forms. Actually LSM is a static analysis, which makes it possible to consider seismic forces in the same way as other static loads. Dynamic characteristics of the reviewed structure – spectrum of the structure natural frequencies, attenuation characteristics – are considered in this method too.

Seismic stability dynamic analysis method (DAM) is a method of numerical integration of motion equation used for the review of the forced vibration of the structure under seismic impact assigned with the earthquake accelerograms.

In the design programs dynamic analysis is based on the following general equation of motion in matrix form

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F^a(t)\}$$

where $[M]$ is mass matrix; $[C]$ is resistance matrix; $[K]$ is rigidity matrix; $\{\ddot{u}\}$ is unit acceleration vector; $\{\dot{u}\}$ is unit speed vector; $\{u\}$ is unit movement vector; $\{F^a(t)\}$ is load vector; (t) is time.

Requirements to the design model when assessing seismic strength of the equipment following the static method are the lowest. For that method it is sufficient that the model conforms to the real structure only in weight characteristics and main geometrical dimensions.

Design models for Strength Analysis following LSM and DAM methods should have dynamic characteristics of the reviewed real structure – spectrum of the structure natural frequencies and identical damping parameters.

It is a problem to form in practice the design model of processing equipment adequate to the real structure not only upon the natural dynamic characteristics (variation shapes and frequencies) but upon the damping character without experimental researches because the connective pipelines and erection conditions will influence on the dynamic characteristics. It is obvious that the connected processing pipelines will influence minimally on the large-scale equipment. That is why it is expedient to follow LSM at the stage of equipment designing, because it is less labour-intensive in comparison with DAM. Moreover, it is characterized with relative simplicity of analysis procedure as well as obviousness of the obtained results. At that, it is better for the equipment with connected pipelines for rigidity evaluation to accept not the fixed values of the first natural frequency obtained by calculation but an interval of values determined by expert assessment. Expert assessment should be based on the accumulated experimental and static data. One of the sources of experimental data may be constantly added computer data bank of the reference spectra data [1]. Let us review the process of initial material formation for expert assessment based on vertical units, which look like pressure vessels and rest on three supports. Montejus, filters and heat exchanges applied in power engineering have such a structural design.

Supports of the vessels accepted for review in this paper are the pipes welded to the device head and equipped with the support plates. The whole structure is fixed to the foundation by means of the support plates using anchor bolts.

Let us review the test results and seismic stability analysis results by an example of the vapour condenser installed at the first power unit of “Volgodonsk” NPP. The reviewed unit looks like a vertical heat-exchanger with three supports. The inside diameter of the shell is 600 mm; dimensions of the support pipes are Ø108x5 mm, support plate thickness is 10 mm. The height of vapour condenser with the supports is 1500 mm. The unit mass with medium is 495 kg.

Prior to the formation of the design model the drawings of heat exchanger as well as the conditions of its fixing were thoroughly studied in order to make the model maximum accurately and assign the boundary conditions more definitely. Design model of the heat exchanger was made using program the “Zenit–95” [2] and is illustrated in Fig. 1.

Values of the first two natural vibrations of the unit determined using the program "Zenit–95" [2] are presented in Table 1.

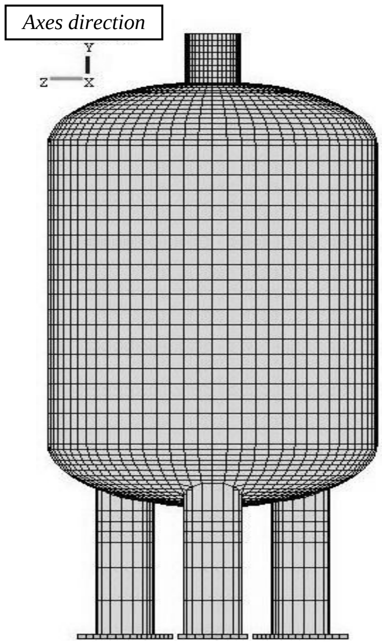

Fig. 1 Design model

Frequencies obtained as a result of the experiment were determined by analyzing the extinguishing free vibrations. At that, impulse excitation method of equipment free variations using single power impulses was used. Single force impacts were applied to this heat exchanger in two inter-perpendicular directions. Registration and analysis of excited vibrations of the heat exchanger was performed using vibration single-channel analyzer "Topaz". Sensor fixing places and force impact direction are shown in Fig. 2. Experiment results are presented like diagrams in Figs. 3 and 4. Values of the first two natural frequencies of the heat exchanger obtained as the result of the experiment are presented in Table 1 too.

As it is seen from Table 1 the frequency values obtained as the analysis result not considering the connected pipelines are different from the values obtained by experiment. The difference for the first frequency is 1.5 Hz, for the second one it is 3 Hz.

In order to check the correctness of the design model the pin elements, which copy the arrangement of the available connected pipelines, will be added. Values of the first natural frequencies after adding the pipelines (see Table 1) are mainly the same as the experimental data. This proves that the design model is formed correctly.

In the same way the influence of the connected pipelines was analyzed also for some similar units. Technical characteristics of these vessels are indicated in Table 2.

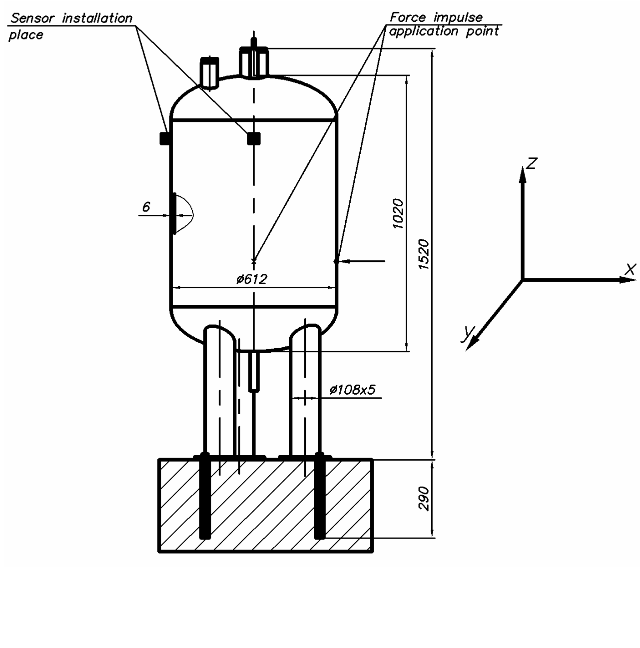

Fig. 2 Sensor installation places

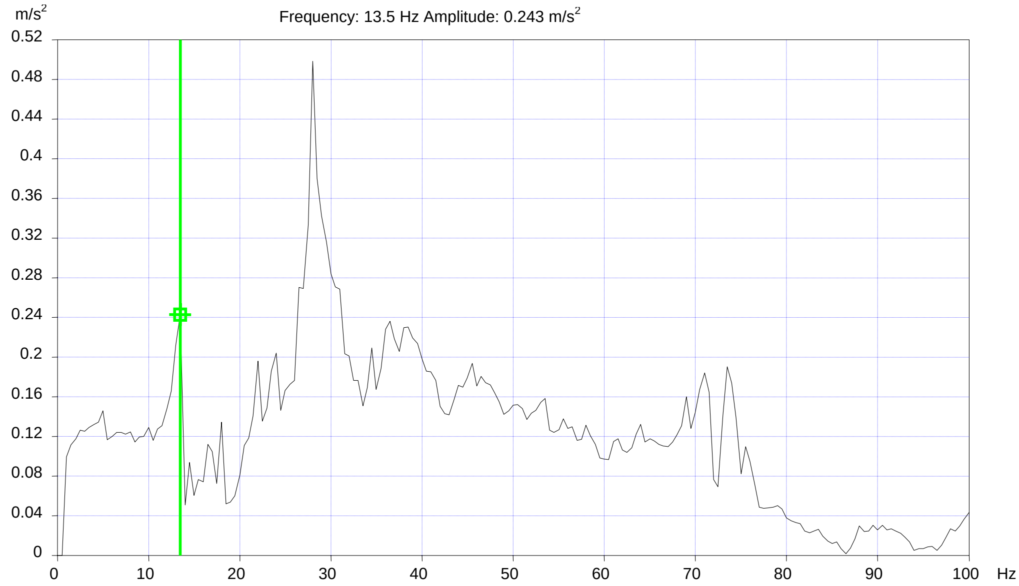

Fig. 3 Spectrum of natural frequencies of the heat exchanger (direction X)

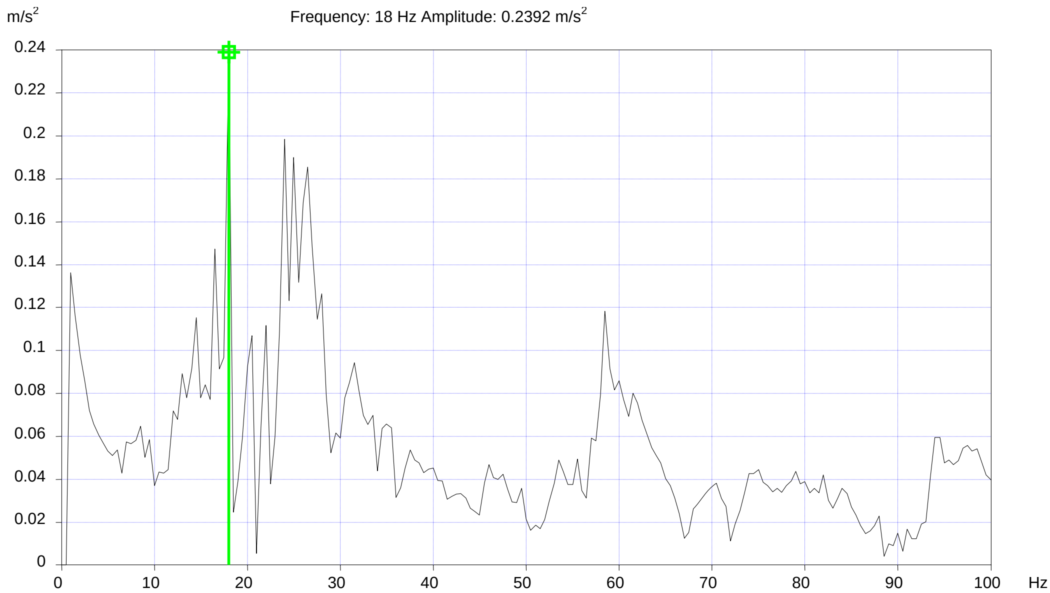

Fig. 4 Spectrum of natural frequencies of the heat exchanger (direction Y)

Table 1

Vibration natural frequencies

	Natural frequency, Hz	
	The first	The second
Frequency obtained as a result of analysis without connected pipelines	12.0	15.0
Frequency obtained as a result of experiment	13.5	18.0
Frequency obtained as a result of analysis with connected pipelines	13.5	18.5

Table 2

Technical characteristics of the analyzed units

Equipment description	Mass, kg	Height, mm	Diameter, mm	Support pipe dimensions, mm	Type of support plate fixing to foundation
Gas cooler	745	1700	600	Ø108x5	One anchor bolt
Buffer tank	5000	3100	1400	Ø159x6	One anchor bolt
Tank – hydraulic lock	138	1700	500	Ø108x5	One anchor bolt
Mechanical filter	8630	3900	3000	Ø273x10	One anchor bolt
Combined type filter	3820	4700	2000	Ø219x6.3	One anchor bolt
Precoat filter	1020	2000	800	Ø76x4.5	One anchor bolt
Combined type filter	3140	4700	2000	Ø219x6.3	One anchor bolt

Analysis results of equipment models presented in Table 2 proved the following: the difference of design model and experimental data is 4 Hz for the units of 150 kg mass, and this difference is less, approximately by 2 Hz, for the units of 500 – 750 kg mass; the difference is very small, less than 1 Hz, for the units of more than 1500 kg. As for the second natural frequencies of vibration, the influence of the connected pipelines on the values of these frequencies is more significant. For the reviewed units the difference of the second natural frequencies of the design modes and experimental data is 3 – 6 Hz. Different degree of the connected pipelines influence on natural frequencies of the unit vibration means that the large-scale units have higher rigidity and mass in comparison with the light ones and the connected pipelines are similar for both.

3. Conclusion

Based on the above-mentioned it is possible to make a conclusion that when designing simple vertical units resting on vertical supports it is necessary to consider the influence of connected pipelines. For “small” units the range of natural frequency change should be 3-4 Hz, and for the large ones 1-2 Hz. It is allowed not to consider the connected pipelines only if the unit mass is greater than 1500 kg.

The application of probabilistic design models with the increased range of natural frequencies will lead to reliability raise of the performed analyses for external dynamic loads and will make it possible to decrease the probability of making adequate inertia loads lower when connecting the pipelines.

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SKAIČIUOJAMŲJŲ MODELIŲ KŪRIMO, ATLIKUS ĮRENGINIŲ DINAMINĘ ANALIZĘ, YPATUMAI

R e z i u m ė

Straipsnyje nagrinėjami skaičiuojamųjų modelių, skirtų technologinių įrenginių stiprumui įvertinti, veikiant išoriniams dinaminiams veiksniams, kūrimo klausimai. Pasiūlyti konkretūs būdai, kaip naudojant vertikalius slėgio indus nustatyti prijungtų vamzdynų įtaką.

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PECULIARITIES OF DESIGN MODEL FORMATION AT DYNAMIC ANALYSIS OF EQUIPMENT

S u m m a r y

Aspects of design model formation for strength assessment of processing equipment under external dynamic impacts are reviewed in the paper. Definite methods for considering the influence of connected pipelines are suggested by the example of vertical pressure vessels.

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ОСОБЕННОСТИ СОЗДАНИЯ РАСЧЕТНЫХ МОДЕЛЕЙ ПРИ ДИНАМИЧЕСКОМ АНАЛИЗЕ ОБОРУДОВАНИЯ

Р е з ю м е

В статье рассмотрены вопросы создания расчетных моделей для оценки прочности технологического оборудования при внешних динамических воздействиях. Предложены конкретные методы учета влияния присоединенных трубопроводов на примере вертикальных сосудов, работающих под давлением.

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