Model Pilot Study Statement of Filled Shells Constructions under Dynamic Impact

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Abstract. Formerly uninhabitable Russian territories at earthquake risk are appropriated for exploitation while ancillary development of necessities of life. In this regard, new facilities construction and existing facilities reconstruction in the field of transport, energy industry and other sectors are expected. Combined constructions (e.g. – soil-filled shells) have been increasingly used in construction. Above-mentioned constructions scope of use is potentially wide and if properly estimated they could adequately meet necessary requirements. Nowadays there is an insufficient discussion of construction interaction with the bulk filler and ground foundation, which results in current calculation methodology not covering significant areas of baseline estimate. Thus, the problems of stress-stain state study of these constructions under the dynamic impact remains relevant.

1. Introduction

Russian Far East vast territories are located in Pacific Rim earthquake belt. Lately, there has been an expansion of such lands development, formerly considered practically uninhabitable.

According to the Strategy [1], Far East and the Baikal region, comprising large area of the Russian Federation, is insufficiently developed in the sphere of transport and energy industry. To solve the problems of underdeveloped transport and energy industry, intensive construction of facilities for infrastructure development is expected.

Metal and reinforced concrete filled shells can be applied in new facilities construction and existing facilities reconstruction, e.g., while transportation facilities construction (berthing facilities, coast protecting structures (figure 1a); supports and foundations of bridges and culverts (figure 1e, f); underground facilities, as well as load bearing structures of transport culverts (figure 1b)); energetic facilities and in mechanical engineering (tanks, cisterns (figure 1 c, d)). Shells might be used in industrial construction and civil engineering for building of retention walls, foundation and base construction, foundation soil reinforcement and as framework of cylindrical elements [2],[3].
Figure 1. Examples of filled shells use in building constructions. a – berthing facilities, coast protecting construction; b – bridge foundation; c, d – fuel tank in the ground; e, f – multiple-block culvert.

Scientific uncertainty of such components of the construction, as shell itself, its filling, foundation and their interrelation makes construction and design process a complex matter [3], [4].

Consequently, the task of stress-stain state character study of filled shells constructions under the dynamic impact specifically tailored for interaction with thin filled shell and soil foundation remains relevant.

2. Calculation of filled-shell construction under seismic load

The issue of engineering in high seismicity areas continues to be one of the most challenging one [6]. This problem is often preceded by two main reasons: uncertainty for earthquake load defining; modelling soil-foundation-construction system complexity.

The first problem is decided differently: earthquake load is possible to defined using a linear spectral method, dynamic methods with finite element method.

On linear spectral method, earthquake load is estimated as maximum possible, whereas it is replaced by a permanent load in strength and sustainability calculations. This replacement results in the excessive stocks in designed constructions. [6].

In accordance with [7] facilities construction and foundation calculation in seismicity areas must be performed on basic and specific load combination bearing in mind estimated seismic load.

In buildings and structures calculation estimated seismic loads are mostly identified by means of console estimated dynamic method (picture 2). The effect of loads and construction elements weight are taken to be focused in the estimated scheme nodes.
Figure 2. Console estimated dynamic scheme of the construction.

Estimated seismic load $S_{ik}$ (kN) in the activity site $k$ (from 1 to $n$) of the estimated dynamic scheme and related to $i^{th}$ natural frequency tone of the construction, is determined to the formula [7]:

$$S_{ik} = K_1 K_2 M_s g A_i \beta_i K_r \eta_{ik}$$  \hspace{1cm} (1)

where $K_1$ - ratio, which takes into account damage according to the construction; $K_2$ - ratio, which takes into account constructive solution; $M_s$ - construction mass, relating to the site $k$ of the estimated dynamic scheme, $t$; $g$ - acceleration due to gravity, m/s$^2$; $K_r$ - dissipation ratio; $\eta_{ik}$ - seismic force ratio on the contraction, depending on construction deformation form at its natural frequency on the $i^{th}$ tone (vibrational pattern ratio), estimating according to formula 5 [7]; $\beta_i$ - dynamic ratio, relevant to the $i^{th}$ tone of the construction natural fluctuation, according to [7]. This ratio focuses on the oscillator acceleration spectrum and maximum acceleration. Spectral curves, proposed in the regulative documents to determine dynamic ratio do not cover all possible cases [8]. $A_i$ - estimated acceleration in the construction foundation in fractions of $g$ (seismic ratio) is defined according to p. 6.4 [7]. Ratio $A_i$ defines amplitude acceleration level. Ratio values correspond to acceleration, specified in MSK-64 scale. However, two circumstances should be taken into consideration, which limit full description of the seismic effect: 1) behavioral description lack of modern earthquake resistant constructions and buildings, 2) seismic effect differences on the different soils at the equal vibration amplitudes. Precise wide range sample data reveal the necessity to increase the meaning of maximum acceleration [8].

Thus, maximum acceleration amplitude $a_{max}$, velocity fluctuations $V_{max}$ serve as the main important components for description of dynamic impact by means of which are expressed dynamic ratio and foundation estimated acceleration.

For filled shell hydraulic engineering structures seismic load calculation is recommended to perform basing on [9]. According to [9] prima facie it is possible to carry out calculation in mode of the estimated scheme of the construction rotation on a seismic angle.

Estimated scheme of the construction is reformed, as well as soil and pier cargo characteristics in the pier are corrected. Front wall in the reformed estimated scheme is imputed as a vertical one (picture 3).

Pier and underground surface, as well as soil layers get an additional inclination on a seismic angle $e_y$ from baseline, determined to the formula:

$$e_y = \arctg A_{sy},$$  \hspace{1cm} (2)

where $A_{sy}$ - effective seismic ratio, mid-ranged through the bulk of the structure moving part, determined to the formula 9.3 in [9].
Further the recalculation of main soil characteristics was performed. Soil and cargo weight on the pier is corrected to the formula 9.6 [9].

![Figure 3](image_url)

**Figure 3.** Scheme to the overall sustainability calculation while estimated scheme rotation on a seismic angle $\varepsilon_y$: a) baseline incision; b) reformed (rotated on the angle $\varepsilon_y$) incision (front wall is imputed as a vertical).

Additionally, a soil internal frictional angle decreasing is performed, due to reduced shift resistance in dynamic effect. Inertial water influence, contacting with the front wall from the body of the waterside, is taken into account as attached water mass. Simplified preliminary calculation algorithm is given in [9], Appendix E. Calculation is limited to construction statistic calculation with aggregated load on it.

As a design result, construction has more safety margin, from the other point, there is material overexpenditure, negatively influencing on economic side of the project.

3. **Setting the objectives of the experiment**

Experiment setting supposes model design of the construction under investigation. Construction under investigation is a fragment of the retaining wall from thin shells of large diameter a total of three, with filing.

It is necessary to ensure dynamic load modeling on the construction model placed in the tray with soil. Dynamic load must present fading fluctuations of a definite frequency, simulating real seismic impact. Sensors of dynamic fluctuations and displacement sensors or strain gauges enable to measure and record relevant parameters of the dynamic impact. Experiment setting is planned in the laboratory conditions. Experimental model is placed on the seismoplatform.

It is planned in the experiment:
- To define initial estimated dynamic parameters of the system: vibrovelocity $V_{\text{max}}$, vibroacceleration $a_{\text{max}}$, displacement $\delta$.
- To record deformation development under dynamic load.
- To determine stress modifying relationship in the shell body under dynamic impact.

4. **Test facility design**

Seismoplatform was designed on the department of hydric, theory of buildings and structures of the Far Eastern Federal University elaborated by I.G. Kuznetzov (picture 4).

On the initial stage of the experiment the required jamming of the springs is defined, a peen mass is given, and height or start peen position angle for the seismoplatform are calculated.

After that soil is placed into the tray. Constructions model and required according to the test number of sensors of dynamic fluctuation are being set. In the case of necessity, strain gauges to record strain in the construction model could be installed. Relevant cargo is placed into the peen to provide the needed mass. Then the peen is displaced from equilibrium into the start position and
discharge is released. After peen hitting the chisel hammer of the soil tray, the last-mentioned performs fluctuations of the required frequency in the horizontal direction.

Figure 4. Seismoplatform: a – side view, b – top view. 1 – metal framework, 2 – soil tray, 3 – soil, 4 – lower part of the tray (frame), 5 – wheels, 6 – foundation, 7 – springs, 8 – immovable support, 9 – chisel hammer, 10 – peen, 11 – metal frame with a loop for peen suspension, 12 – dynamic fluctuation sensors, 13 – construction number, 14 – motion sensors, 15 – frame for trigger mechanism.

5. Defining calculation parameters of the facilities

While experiment preparation spring rigidity $k$ is defined (picture 4), enabling the required fluctuation frequency.

At a known weight of the system $Q$ soil tray and known spectrum of the load-bearing frequency $\omega$ ($\omega_{\text{min}}$÷$\omega_{\text{max}}$) of the most likely earthquakes in the area, total spring rigidity $k$ of the experimental set, providing a given spectrum of its own fluctuations, equals [5]:

$$ k = \left[2\pi(\omega_{\text{min}} + \omega_{\text{max}})^2 \frac{Q}{g}\right] $$

(3)

Primorsky region area and Japanese Sea are chosen for investigation, where bearing load is from 0.7 to 2.2 Hz [5].

System weight is (tray + soil) $Q=30$ kN, then total required spring rigidity is:

$$ k = \left[2 \cdot 3.14(0.7 + 2.2)^2 \frac{30}{9.81}\right] = (59.1 + 583.7) \text{kH/m} $$

where $g = 9.81 \text{ m/s}^2$ – acceleration due to gravity.

Then, by addressing equation of the preserving, the momentum under elastic impact we get expression to find set start parameters – $h$ – peen height rise and peen vertical angle declension $\alpha$ (picture 6).

Load rise height $h$ is (picture 6):

$$ h = \frac{V_\alpha^2}{2g} $$

(4)

where $V_\alpha$ – start peen velocity. Actual peen weight without load is $m=70$ kg, velocity, which needs to be given to peen to get fluctuations is $V_\alpha=5.8$ m/s. Peen rise height is $h=1.71$ m.

Peen angle deflection is (picture 6):

$$ \alpha = \arccos(1-h/L), $$

(5)

$\alpha = 37.81^\circ$

where $L$ is peen suspension length (distance from fulcrum to peen) $L=1.5$ m.
Construction under investigation is a thin shell, retained in the design position mainly due to inner filler work. Modeling condition of shell material and condition, as well as filling material (more often it is soil) must provide total similarity of tensed condition of nature and model in the accepted soil schematization. To solve this task method of similarity theory and dimensional analysis [10] can be used.

![Figure 5. Peen scheme for calculation initial parameters estimating.](image)

While modeling all model elements length was decreased proportionally modeling. Estimating model parameters have been obtained from the conditions of the geometric similarity. Length scale of the model is accepted \( \alpha = 1/20 = 0.05 \). Parameters of the resulting model are presented in the table 1.

| Parameter         | Model diameter \( d_o \) | Model height \( h_o \) | Model wall thickness \( t_o \) | Material elasticity module of the model \( E_o \) |
|-------------------|---------------------------|-------------------------|-------------------------------|------------------------------------------|
| Unit              | m                         | m                       | m                            | kPa                                      |
| Meaning           | 0.5                       | 0.725                   | 0.004                         | \( 3 \cdot 10^6 \)                          |

6. **Experiment expected results**

During the experiment the model main dynamic characteristics vibrovelocity \( V_{\text{max}} \), vibroacceleration \( a_{\text{max}} \) and displacement \( \delta \) are planned to be obtained. To obtain these characteristics multi-channel vibroanalyzer Vibran-3.0 will be applied. Vibroanalyzer enables to define dynamic characteristics in several sites of the system. Data measurement to characterize dynamic impact will provide to draw up correct description of dynamic load impact, thus taking into consideration specificities of modern constructions. Besides, the experiment makes it possible to establish the condition of filler soil, foundation and construction interrelation under the dynamic load.

For quantitative estimation of the construction stress-stain state, design of system mathematic model as well as comparison of experimental parameters with parameters from the calculation are planned.

7. **Conclusion**

Design and construction objectives in the areas of heightened seismic activities of the northern territories remain relevant. The current methodologies for calculation are inadequate to ensure consideration of design features of complex combined constructions, such as thin shells, soil- filled ones (filled shells).

In connection with the increasing concern over this objective and economic inappropriateness of its examination in situ, pilot study design under laboratory conditions is planned. During laboratory testing study of effects of dynamic loading on a retain wall fragment from large-diameter filled thin shells is planned. Seismoplatform has been proposed creating dynamic impact on the construction. During the experiment system initial calculated dynamic parameters will be estimated: vibrovelocity...
\( V_{\text{max}} \), vibroacceleration \( a_{\text{max}} \), displacement \( \delta \) to give further calibration of the numerical models stress-strain condition description of the constructions at issue under seismic impact.

References

[1] 2009 Strategiya Soczialno-Economicheskogo Razvitiadalnego Vostoka I Baikalskogo Regiona Na Period Do 2025 Government of the Russian Federation N 2094-p 241 p
[2] Levachev S N 1978 Shells in hydraulic engineering section of the editorial board of Stroyizdat (Moscow: Stroizdat) 168 p
[3] Becker A T, Zimbelman N Ya 2010 The use of shell structures with elastic filler in construction Bull. of the F.E.S.T.U. 2(4) 27-33 p
[4] Zimbelman N Ya, Chernova T I 2012 Model studies of the stress-strain state of shells of large diameter with filler Bull. of MGSU 12 71-77 p
[5] Okamoto Sh 1980 Earthquake engineering (Moscow: Stroizdat) 342 p
[6] Bestuzheva A S, Nguyen Phuong Lam 2010 Dynamic and spectral methods for determining seismic load acting on a structure during an earthquake Bull. of MGSU 155-168 p
[7] 2018 Stroitelstvo v seismicheskikh raionakh Updated edition of SNiP II-7-81 *SP 14.13330.2018 Standartinform (Moscow) 122 p
[8] Steinberg V V, Sachs M V, Aptikaeve F F ect. 1993 Seismic impact assessment methods 90 p
[9] 2001 Rukovodstvo po uchetu seismicheskikh vozdeistvi pri proektirovani morskikh gidrotekhnicheskikh sooruzenii RD 31.3.06-2000
[10] Zimbelman N Ya, Chernova T I 2012 Setting up experimental studies of large-diameter shells with filler Vologda readings pp 16-17