Estimation of seismic load to the oil pipeline with manholes

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Abstract. Estimation is to predict the outcome of seismic load to underground pipeline with manholes. Forces and shears were taken into account during modelling of seismic resistance. There were 3 types of waves identified in this job, and the estimation of the maximum velocity of the soil movement was made according to the category of soil by seismic properties. The seismic resistance was estimated under the action of both horizontal and vertical directions of seismic load. The model of a manhole was created from scratch by authors. The main supporting elements of the body were modelled in a stress-deformed mode. The transmission of seismic longitudinal P-waves was simulated with parameters up to 9 points inclusive at the MSK-64 scale in soils of medium density. Based on the analysis of the data obtained, a graph of maximum equivalent von Mises stresses was built depending on the phase of the seismic longitudinal P-wave transmission. Conclusions were made about the efficient usage of applying the proposed approach to solve this class of problems.

1. Introduction

Design and selection of materials for pipeline constructions are being chosen based on several criteria [1-9]. First is material choice is based on climate. Besides of that it is very important, what kind of environment will be transported as well as characteristics of the mobility of the earth's crust. The static and dynamic forces are acting onto pipeline, like its own weight (weight of pipeline construction, isolations, linings, transported products), weight of soil backfill, reaction of soil itself, hydrostatic pressure inside, influence of temperature, compression and stretching of pipeline during earth’s crust movement in faults and seismic load in longitudinal direction. At the current moment this is an actual objective to estimate existing methods proving reliability of pipelines at the zones of active movement of earth’s crust, like manholes.

Manholes should be built in earthquake resistant execution for areas with seismic risk up to 9 points inclusive as per MSK-64 scale.

Manholes in earthquake resistant execution must be durable, reliable and impervious while working and after seismic load up to 9 points inclusive as per MSK-64 scale.

2. Generalities

Forces and shears in manholes were defined by its simultaneous deformation with nearby soil while seismic waves are passing through. During modelling when seismic waves are passing through different cross-section area of manholes, thus creating additional forces and shears, which have to be taken in account as well as [1, 2].
Forces and shears in pipelines related to seismic waves transmission have to be divided into following types:

- longitudinal (P-wave);
- transverse (S-wave);
- Rayleigh wave (R-wave).

All three type of waves have their own velocity of propagation in different soils: \( V_P, V_s, V_R \), length of wave: \( X_P, X_s, X_R \) and shearing direction of points of soil body relatively to direction of the wave propagation (Figure 1). Front of the wave is moving along some certain vector, and places with maximum shear of soil in different moments of time could match with different cross section area of manhole.

![Figure 1. P, S, R waves are passing through soil and creating movement of its different parts.](image)

3. Methodology of research

To identify reaction of each cross-section area of the manhole, the worst case scenario of phase, direction and type of seismic wave should be analyzed. The manhole has a complicated 3D configuration, that is why several estimations will be made up for different type of waves and theirs phase shifts. Epicenter of earthquake could be located in any direction from manhole, therefore it’s necessary to look at several possible ways of propagation of seismic waves. Once estimation of each cross-section area of manhole has done, then worst case scenario of this result will be chosen to be used later on.

In case of conditions of seismic resistance aren’t met, the manhole should be redesigned, and estimation will be conducted again.

Soil, surrounding the manhole, is modelling like in static estimation with big amount nonlinear and elastic connections, which set with special step along and perpendicular to the axe of manhole in vertical and horizontal directions. And in this case, it should be used dynamic Young modulus of soil and Poisson ratio, identified at seismic survey. Adhesion and internal friction factor of soil will be used same as in static estimation.
Seismic waves transmission is modeling by forced shift of connections described relationship of manhole and soil according to soil deformation while proper type and direction of seismic waves are passed through and calculating forces and stresses of this manhole in these conditions.

It should be analyzed several options of movement of P, S, R - waves and several options of theirs phase shifts.

Maximum speed $V_{\text{max}}$ of soil movement at the time of earthquake need to be identified according to data of seismic velocigrams. If there are no such data, then $V_{\text{max}}$ is recommended to be chosen according to category of soil by seismic properties:

- soft ground (category III)
  
  $$V_{\text{max}} = 0.12 A_{\text{hor}}^{\text{max}} K_{A}$$

- rocky ground (category I & II)
  
  $$V_{\text{max}} = 0.91 A_{\text{hor}}^{\text{max}} K_{A}$$

Maximum horizontal and vertical soil shift at earthquake have to be identified according to data of seismograms.

In case of absence this data of surface pipelines, maximum horizontal shift of soil could be calculated using formula below:

$$D_{\text{hor}}^{\text{max}} = \frac{6V_{\text{hor}}^{2}}{A_{\text{hor}}^{\text{max}} K_{0} K_{A}}$$

$$D_{\text{ver}}^{\text{max}} = D_{\text{hor}}^{\text{max}} K_{v}$$

Velocities of propagation $V_{P}$, $V_{S}$, $V_{R}$ in a soil body must be chosen according to data of seismic survey. It’s assumed to use these parameters from reference seismic survey during design phase.

Velocity of Rayleigh wave could be calculated using formula below:

$$V_{R} = k V_{S}$$

where coefficient $k < 1$ is the root of an equation:

$$\frac{1}{8} k^6 - k^4 + \frac{2}{1 - v_{\text{din}}} k^2 - \frac{1}{1 - v_{\text{din}}} = 0$$

where $v_{\text{din}}$ — dynamic Poisson ratio of soil.

Seismic resistance is defined where both horizontal $j=\{X,Y\}$ and vertical $j = \{Z\}$ direction of seismic load are acting together and assumed that values of seismic loads in each direction could be defined separately.

Maximum horizontal acceleration at free surface of soil at earthquake must be defined according to data of seismic regionalization and micro-regionalization, which acquired based on analysis of accelerogram of previous earthquakes in this areas or areas which have same seismic properties. Maximum values of acceleration should be not less, than values shown in table 1 for Russian Federation, and for different areas according to the national standards.

| Estimated seismicity of site “lsite”, points | 6 | 7 | 8 | 9 | 10 |
|------------------------------------------|---|---|---|---|----|
| Seismic acceleration, m/sec$^{2}$       | 0.5 | 1.0 | 2.0 | 4.0 | 8.0 |

Ratio of relationship between vertical and horizontal amplitudes of acceleration $K_{V}$ is based on seismic micro-regionalization data, otherwise should be equal to $K_{V}=0.7$. 
4. Modelling of manhole in a stress-deformed mode

Modelling of dynamic load into equipment, for example, the wave is passing through it and in case of exception in normal working conditions had occured at hazardous site of facility, shows, stress-deformed mode could potentially reach safe working limits of construction and requires application of protective devices [15].

Solid-state model of assembled manhole made according technical specifications[8] was used in modelling of stress-deformed mode. Main supporting elements are partially located inside of soil and dynamic load (9 points is characterized by: “sandy funnels” in soils with excessive sand; widespread landslides; ground fracturing; damage: non-armored bricks; damage of medium level: not enough armored concrete, underground pipelines) was analyzed without relationship with pipeline. To be able to model this relationship it needs to consider location of particular pipeline and properties of soil.

Model of manhole is shown below on Figure 2.

![Figure 2. Model of manhole.](image)

Stress-deformed mode was analyzed during modelling of main supporting elements of manhole [10-14]. Seismic load onto secondary supporting elements of manhole haven’t been analyzed. The transmission of seismic longitudinal P-waves was simulated with parameters up to 9 points inclusive at the MSK-64 scale in soils of medium density. Distribution graph of equivalent von Mises stresses at outer part of manhole depending on the different phase of the seismic longitudinal P-wave transmission shown at Figures 3-5. Model of manhole wasn’t shown there for better visualisation.
Based on the analysis of the data obtained, a graph of maximum equivalent von Mises stresses was built depending on the phase of the seismic longitudinal P-wave transmission, shown at Figure 6:
Finally, result of modelling of seismic load up to 9 points inclusively at MSK-64 scale, shows, that maximum equivalent stress equals to 40000 Pa (0.04MPa), which means that this is very low for steel material, which was used to produce a body of manhole. That is proves reliability of this construction.

Such method of modelling of technically complicated constructions may be applicable with uncertainty of input data, as well as it allows to change main parameters and analyze possible consequences.

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