EFFICIENCY OF TRENCH BARRIERS USED TO PROTECT STRUCTURES FROM DYNAMIC LOADS AND STUDY OF STRESS-STRAIN STATE OF SOIL USING STRAIN-HARDENING MODEL OF SOIL BEHAVIOUR

This study consists in numerical modeling of the nonlinear response of soil. The study is a research into the protective performance of both open and in-filled trenches and an examination of the influence produced by (1) the shape of trenches and (2) their position in relation to sources of vibration and structures on the isolation efficiency of barriers. Assessments were based on reduction in horizontal displacements of soil particles on the ground surface exposed to impulse loading. Also, results of numerical researches are analyzed and interpreted to provide recommendations for their implementation and guides for barrier designers. Three points of loading were analyzed and an attenuation curve of soil displacement was drawn; the curve follows the projected trends, as it decays in the horizontal direction on the ground surface. The structure produces substantial effect on the efficiency of open barriers in terms of the surface wave energy.

Key words: vibration reduction, wave barrier, soil response, wave propagation, strain-hardening model of soil behaviour.

Wave barriers are on the list of the most effective methods used to protect structures from surface waves. In the three past decades, extensive researches were performed by numerous researchers, including Russian scientists, into the efficiency of barriers preventing propagation of the surface wave energy in soils [1—4].

In this study, FLAC software package was used to develop a 2D finite difference element model to simulate the efficiency of open and in-filled trench barriers preventing the propagation of surface waves, if structures are within their propagation trajectory. A constitutive strain-hardening model of the soil behaviour was also employed to implement the research project. The choice of an appropriate constitutive model may produce a major influence on the numerical results of the finite difference element analysis of geotechnical problems. The constitutive model must be able to capture the main features of the mechanical behavior of barriers in complex states of stress. General strain-hardening parameters to be incorporated into numerical and analytical methods have been developed on the basis of the findings of standard tests.

In this research, an extensive study of the influence of various parameters such as geometric dimensions of the barrier trench (D as the depth), the barrier (wall and in-filled material), and the distance from the barrier to the source of disturbance (X) is performed, assuming that L, being the distance from the barrier to the structure, is constant. The results of the parametric study will be presented in the form of an averaged amplitude reduction ratio. Measurements were taken for each of the three selected points of loading between the trench and the structure in five stages (no trench, open trench and in-filled trench). Three loading scenarios, based on different
locations of the trench and the structure, were used in this analysis. The points of loading were located at the distances of 3.0, 8.0 and 16.0 m from the trench.

Soil behaviour was simulated in a half-space. The structure was approximated to an equivalent rectangular shape, it was 10 m wide and 15 m high; it was located on the right side of the barrier on the ground surface, and the foundation of the building was assumed as the mat one located at the depth of 1.0 m below the ground surface. In this paper, the authors assume that the soil surface having a one meter diameter and located on the left side of the barrier is exposed to the vertical impulse dynamic load of triangular shape (exposure duration = 0.1 second). Maximum dynamic load is $P = 1.0$ MN at the peak point.

Dynamic properties of the soil materials used in the tests are specified in ref. [5] (see Table 1). Properties of the concrete and the structure are assumed as linear, the model is elastic, and the soil material is assumed as non-linear. All geometrical parameters of the model are provided in ref. [6] (see Fig. 1 and Table 2).

2D finite difference element models were studied by comparing the findings of the analysis of models with the strain-hardening behavior of the soil in terms of the attenuation amplitude of displacement of the surface ground ($A_r$) (see Eq. 1 ref. [6]).

An important point that must be mentioned is that the majority of researches are focused on the effectiveness of barriers, if there is no structure present, and on the elastic behaviour of soils exposed to sinusoidal and regular excitation dynamic loads. However, in this project we have studied the influence produced by the structure and the nonlinear behaviour of soils on the effectiveness of barriers exposed to impulse loads.

Figures 1a, b, c demonstrate the values of reduction ratio $A_r$ for the cases of open and in-filled barriers with the presence of the structure ($X=3.0$, 8.0 and 16.0 m, $D=10$ m, $W=0.5$ m and $L=3$ m).

The figures have proven that the registered displacement amplitude ratio goes down and follows the anticipated trends in terms for all type of barriers. The value of $A_r$ ratio increases from the barrier to the structure and along the foundation of the structure, but barriers demonstrate good overall results in attenuating the wave energy in terms of displacement of soil particles.

Fig. 1 demonstrates that displacement ratio curves in open trenches in the range of 5 to 10 m behind the structure incline as expected, but in the in-filled ones, the curves of displacement ratios behave differently. Also, the value of the amplitude ratio ($A_r$) underneath the foundation of the structure increases significantly in respect of all types of barriers. So, the conclusion is that the presence of the structure reduces the efficiency of barriers.

It is noteworthy that at the point located 70.0 m from the source of disturbance attenuated displacement amplitude is negligible. Therefore, the analysis of barrier effectiveness can be limited to the distance of 70.0 m from the source, as at larger distances amplitudes are negligible, even without any wave barriers.

The influence of the barrier width will be ignored in this study, since the proposed width of open and in-filled trench barriers is 0.5 m. Therefore, performance of barriers will be assessed on the basis of their depth and shapes, while the source-to-barrier-to-structure distance remains constant.
Fig. 1: Calculated amplitude of horizontal displacement reduction ratio, depth of trench – 10 m, W=50 cm and L=3m) at the first point, 3.0 m, b) at the second point, 8.0 m, c) at the third point, 16.0 m

Figures 2a, b, c, d demonstrate reduction ratios of soil displacements for the four depth values of trench barriers (D = 5, 10, 15 and 20 m) and open and in-filled situations. The structure is located at the distance of 25 m to the right of the trench (L=25 m), and the disturbance source is located at the distance of 8 m to the left of the trench (X=8.0 m). Barriers having various depth values showcase different efficien-
cies in reducing the energy of surface waves under impulse loads with the presence of the structure, and it is also evident that the amplitude reduction ratio for various depths of barriers changes randomly. This may be explained by the three reasons: first, the structure vibration under dynamic loading can affect the vibration of soil particles on the earth surface; second, reflected waves at the soil-to-barrier interface underneath the barrier are in-phase or out-of-phase; third, vibration amplitudes are negligible even without a barrier, and any variation in the response causes a substantial change in the ratio.

Behaviour patterns were documented by Woods (1968) in his experimental study of open trenches, by Baker (1994) in his experimental study of in-filled trenches and by Beskos (1986) in his study of sheet pile barriers as vibration isolators [5, 7]. They have identified that the distance to the principal minima decreases as the barrier depth increases; however, in this study, a different behaviour pattern is identified. We can say that the behaviour pattern described in this study is drastically different from the behaviour pattern identified earlier; this difference can be attributed to the presence of structures that can affect the efficiency of barriers.

Some extreme points can be identified in Figures 2 a, b, c, d. The presence of a structure and nonlinear soil properties can be considered as the reasons for a different maxima or minima changing with the distance from the barrier. As it is mentioned above, as the distance from the barrier increases, vibration amplitudes get much smaller. When these small values are used to evaluate the amplitude reduction ratio, significant numerical errors are likely to occur.

Figures 2 a, b, c, d show that the clear minima immediately behind the barrier results in a quiet area, and this area can be mentioned as a region for minimum displacements behind the barrier.

Our conclusion is that this study is aimed at development of a few general guidelines for design of vibration isolation actions involving trench-barriers with the presence of structures in the reality context. Protective effectiveness of wave barriers was evaluated by assessing the reduction of soil displacements on the ground surface exposed to impulse loading. The findings can be summarized as follows:

1. For all type of barriers, it is evident that at three points of loading, the attenuation curve of soil displacement decays in compliance with the anticipated trends in the horizontal direction on the ground surface ($A_r < 1$). Along the provisional line connecting the barrier and the structure and along the foundation of the structure this ratio increases, but in the presence of a structure the barriers demonstrate good results in suppressing the wave energy in terms of displacement.

2. In the assumed conditions, the amplitude ratio of horizontal displacement of soil $A_r$ increases significantly and reaches its maximum value underneath the foundation (behind the barrier). This statement is valid for all types of barriers, especially open ones. It means that the presence of a structure behind the trench reduces the barrier efficiency of open trenches.

3. It is observed that barriers having various depth values demonstrate different efficiency values in reducing the energy of surface waves under impulse loadings with the presence of a structure; this may be explained by particular reasons.

4. The results show a minima immediately behind the barrier resulting in a quiet area; this area can be mentioned as a site of minimum displacements behind the barrier.
Fig. 2: Calculated amplitude reduction ratio for a trench located at the second point (X=8.0 m), a) open trench, b) in-filled concrete trench, c) open trench surrounded by a concrete wall (0.5 m)
Fig. 2: Calculated amplitude reduction ratio for a trench located at the second point (X=8.0 m), d) in-filled concrete trench surrounded by a concrete wall (0.5 m)

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About the authors: Orekhov Vyacheslav Valentinovich — Doctor of Technical Sciences, Professor, Department of Soil Mechanics, Beddings and Foundations, Moscow State University of Civil Engineering (MGSU), 26 Yaroslavskoe shosse, Moscow, 129337, Russian Federation; orekhov@rambler.ru;

Negahdar Hassan — postgraduate student, Department of Soil Mechanics, Beddings and Foundations, Moscow State University of Civil Engineering (MGSU), 26 Yaroslavskoe shosse, Moscow, 129337, Russian Federation; hassan_negahdar@yahoo.com.


В.В. Орехов, Х. Негахдар

ПРОГНОЗ ИЗМЕНЕНИЯ НАПРЯЖЕННО-ДЕФОРМИРОВАННОГО СОСТОЯНИЯ ГРУНТОВЫХ ОСНОВАНИЙ ПРИ ТЕХНИЧЕСКОЙ ЗАЩИТЕ СООРУЖЕНИЙ ОТ ДИНАМИЧЕСКИХ ВОЗДЕЙСТВИЙ

С ИСПОЛЬЗОВАНИЕМ МОДЕЛИ ДЕФОРМАЦИОННОГО УПРОЧНЕНИЯ ГРУНТА

В основу исследований заложен комплексный подход к решению поставленной задачи, включающий научный анализ и обобщение материалов по применению полуоткрытого способа строительства барьеров для защиты строительных конструкций от поверхностных волн при динамической нагрузке, при этом все этапы строительства рассматриваются во взаимной связи. Моделирование играет важную роль при изучении сферы взаимодействия инженерного сооружения с геологической средой. Для решения таких геотехнических проблем, как несущая способность основания, устойчивость подпорных стенок, при условии работы основания вдали от предельного состояния математические модели могут быть сформулированы в замкнутой аналитической форме: уравнения упругости и пластического течения с упрочнением — Hardening Soil.

При проведении исследований по определению эффективности моделей системы барьер — строительные конструкции использован метод конечных разностей (МКР), реализованный в программном комплексе FLAC2D. Представлены результаты численного моделирования нелинейной реакции грунтов основания при исследовании защитной деятельности незаполненной и заполненной траншей против поверхностных волн. Исследовано влияние геометрии траншеи и его местоположения от вибрационных источников и конструкций на эффективность изоляции барьеров. Полученные результаты показывают, что барьеры различной глубины обладают разной эффективностью в снижении энергии поверхностных волн при воздействии вертикальной динамической нагрузки на поверхности грунтового массива.

Учет нелинейного поведения грунтов основания при динамических нагрузках, а также учет в расчетной схеме строительных конструкций, защищаемых барьерами в виде заполненных и незаполненных траншей, представляет собой новый (более совершенный) подход к решению поставленной задачи.

Ключевые слова: вибрации, барьер, реакция грунтов, распространение волны, стрейн-харденинг модель поведения грунта, защита сооружений.
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Об авторах:
Орехов Вячеслав Валентинович — доктор технических наук, профессор кафедры механики грунтов оснований и фундаментов, ФГБОУ ВПО «Московский государственный строительный университет», 129337, Россия, г. Москва, Ярославское шоссе, д. 26, orehov@rambler.ru;

Негахдар Хассан — аспирант кафедры механики грунтов оснований и фундаментов, ФГБОУ ВПО «Московский государственный строительный университет» (ФГБОУ ВПО «МГСУ»), 129337, Россия, г. Москва, Ярославское шоссе, д. 26, hassan_negahdar@yahoo.com.