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Improving the impact behavior of pipes using geofoam layer for protection

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A B S T R A C T

In scope of this study performances of protective layers, proposed to protect the pipes from sudden impact loads such as rock falls, are aimed to be compared. In this study, performance, strength and energy absorption capability of geofoam structures against impact forces are investigated by using drop weight impact testing apparatus. Pipes that are manufactured from steel and composite materials are tested with only 130 mm thick sand protecting layer without any geofoam structure, and with two different geofoam with different thicknesses. Results are presented in a comparative form and the effect of geofoam on the impact behavior of sand layer is investigated. Impact load and accelerations on the pipes are measured with respect to time during experiments. Absorbed energy by the pipes are calculated and compared with each other for determining performance of the different protective structures. From the study, it was observed that the sand and geofoam layers used as protective layers were generally successful by reducing the detrimental effects of impact loads in terms of dissipating impact effects on the pipes and the measured acceleration and displacement levels. The best result is obtained from the 50 mm thick geofoam with sand layer. Finite elements analyses are performed by using ABAQUS software and both test and analysis results are compared to obtain a model that can give an idea to designers.

1. Introduction

In scope of this study, pipe systems are selected for testing and comparing the performance of protective structures under impact loading. A testing apparatus, which simulates the falling rocks, is designed for this purpose. Pipes are important structure systems, which are used for transferring materials from one point to another. Pipes are mostly used for transferring materials such as petrol and natural gas that are used for energy production as well as drinking and waste water transfer. Pipes are long structures that pass along several geographic formations. Possible landslides and rock falls are significant causes of damage to pipe systems especially in mountain sides and valleys. Pipe systems are designed with respect to interior liquid or gas pressure loads as well as exterior dynamic and static loading according to investigated projects. Sudden impact loading such as rock fall or land sliding is neglected in these projects. Impact loading is a significant sudden dynamic loading at which intensity can be bigger than static and dynamic loads. Authors believe that deeper studies about this loading type are required and these loading must be taken into consideration during design phase of the pipe systems.

It is seen that there are few studies about impact effects on pipes after literature review [1–12]. However, there is no study found in the literature about the effects of layered protective structures for reducing the impact loading effects on pipes. Therefore reference test are performed on pipes without using any layered protective structures for comparing and interpreting the performance of different layered protective structures by dropping weight directly onto them. A free falling weight test apparatus is used for applying impact loading to pipe systems and simulating rock falling. After reference test, only 0–7 mm sand material with definite relative compactness ratio and geofoam with sand layer are placed on pipe as a protective layer and then tests are repeated. From the review of the literature, it is observed that the test setup based on the free falling of weights is a conventional and widely used option to simulate the impact loading. Such test setups were used for impact loading test on several types of structures and materials [13–16].

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Thus performance of layered protective barriers, which are made up of only soil and geofoam with soil are compared. Although no study is encountered during literature survey about performance of pipes and effect of protective layers on impact behavior, some selected examples about impact behavior of pipes are summarized. The study conducted by Pichler et al. [1,2] investigated the stress distribution on pipes and penetration depth to gravel that was packed around pipe by changing the energy of impact load applied by falling rocks. Concrete cubes with different weights were dropped from different heights for simulating rock falling in one to one scale. Then a finite element model was prepared by using the results of this experimental study. Finally, a verified analytical model compatible to experimental results was tried to be created.

Yang et al. [3] studied both experimentally and analytically the collusion of two pipes. In the study, a rolling pipe was collided to another supported pipe. The variables in the experimental study were the impact point and change in pipe thickness. In addition an analytical model was also created by using LS-DYNA software. Impact testing of one to one scaled underwater pipes was experimentally tested in the study of Palmer et al. [4]. Falling of the pipes on each other during assembly was experimentally simulated and tested in the study. An impact to inner pressurized gas transfer pipes was experimentally studied by Jones and Birch [5]. Deformation profile on pipes under the effect of impact loading was determined.

Tafreshi and Khalaj [6] studied experimentally about the effects of cyclic loading on buried pipes under roads. The variables that were investigated in the study were burying depth of the pipe, relative compactness value of sand layer above and applied stress value on soil surface. Experimental investigation of underwater pipes that were produced by using fiberglass was conducted by Gning et al. [7]. Damage distribution after impact was investigated by using ultrasonic measurement devices.

Impact behavior of water pipes was studied by Shah [8]. Behavior and deformation distribution of copper water pipes were investigated by applying impact tests in both empty and water filled conditions. Finite elements analyses were also performed with LS-DYNA software by using experimental test data. Experimental and finite elements analyses results were compared.

Protective structures against rock falling were investigated in the study of Mougin et al. [9]. Protective structure, which was designed as energy absorber, was placed under a reinforced concrete slab and an experimental study was conducted. Developed protective structure was designed for structures such as tunnels which were under the risk of rock falling. 1/3 scaled specimen was tested in the field for investigating designed energy absorption mechanism. Performance of the protective structure was determined by interpreting test results.

Bhatti and Kishi [10] conducted experimental studies on a beam that was used as a protective structure in one to one scale under impact loading that simulates rock falling and finite elements analyses were also conducted by using LS-DYNA software for the same structural member. Reinforced concrete beam with protective sand layer was tested by dropping weight from different heights. Then finite elements model was developed in relation to the test results and both results were compared with each other. Fatigue duration of composite pipes was tested under seawater pressure and dropping weights from different heights in the study of Deniz et al. [11]. After submerging composite pipes into the seawater for a certain time, pipes were tested with dropping specific weight from different heights and damage condition was determined by applying inner pressure to pipes.

Guades et al. [12] studied the failure type and behavior of fiber reinforced tubes under axial impact loading. The investigated variables may be stated as the weight of the dropping hammer, impact energy and the number of drops. The general behavior and damage distribution of the composite tubes were investigated under the effect of varying energy impact loading. The effects of impact loading on damage distribution and behavior were investigated.

In light of the summarized literature review and investigated studies, a study is planned about the performance of protective structures for pipe systems that withstand impact loading such as rock falling or land sliding. It is believed that from the results of the study, some methods may be proposed to protecting the pipes from the dynamic impact loads such as land sliding and rock falls. Excessive excavation volumes and costs are inevitable to protect the pipes from such effects by increasing the land fill layer above the pipes. Very long pipe systems with increasing excavations and fills may greatly amplify the project costs. Accordingly, in this study reducing the amount of land fill above the pipe systems is aimed by using additional strengthening layers of geofoams. It is believed that the application of protective layers may lead reduced project cost by reducing the excavation and fill amounts.

In this study, tests are performed for three different protective layers with pipes that are manufactured from two different materials and results are compared with the case of without any protective layer. A constant weight dropping test apparatus is used during tests. A constant weight of 5.25 kg is dropped from 500 mm height and a constant energy impact loading is applied to specimens. Impact behaviors are interpreted by using acceleration-time, displacement-time and load–displacement graphs obtained from tests. Energy absorption capacities of test specimens are calculated using load–displacement graphs. Performances of protective layers are compared by using these data. Tests are modeled by finite element analysis software ABAQUS and both test and analysis results are compared to have a verified model that can be used during design stage.

2. Experimental study

2.1. Test specimens and materials

A constant weight dropping test apparatus is used during this experimental study. A container is produced for modeling rock falling on pipe systems. This container is used during tests for placing sand with 0–7 mm gradation as a protective layer on the pipe system. Tests are performed by placing this container under the testing apparatus to apply the impact loading. Geometrical properties and sizes of pipes used during tests are given in Fig. 1.

Investigated variables in this study are the type of the pipe and protective layer material. Two types of pipes are tested in this study. First one is made up of only steel and the other one is steel covered with bitumen material from outside and concrete from inside. Length and diameter of the pipes are 1000 mm and 220 mm, respectively. Thicknesses of the steel pipe and composite one are 3 mm and 5 mm, respectively. Composite pipe is a steel pipe that is covered by 1 mm bitumen and concrete from outside and inside, respectively. Three different protective layers placed above the pipes are used. These three protective layers are only 130 mm thick sand with a 0–7 mm gradation and sand with 30 and 50 mm geofoam layer reinforcement. Totally eight specimens are tested in this experimental study. Two of them are tested without protective layers as a reference and remaining six specimens are tested with different protective layers. Properties of specimens are summarized in Table 1.

Specific weight, maximum and minimum density values and distribution of grain diameters of well graded sand (SW) used during experiments are characterized with tests. The results of