# Experimental Study on Pipe Sections against Impact Loading

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***Abstract*** **– Pipelines are significant structural systems that transfer necessary materials from one place to another. They are under the effect of static and dynamic loads during their service lives. Investigations have become important to determine the effects of sudden dynamic loads with technological developments. Researchers study the mechanical properties of different materials and structural members under dynamic effects such as earthquake, wind, blast, rock falling and vehicle crushing. For this purpose, different test setups have been developed to investigate the behaviour of test members. In this study, galvanized and water filled galvanized pipe sections having three different diameter values are produced in a laboratory to perform tests under impact loading. The behaviour of the pipes is determined by free falling test apparatus. In addition, measurement devices as accelerometer, dynamic force sensor, lvdt, and data logger are used in the experimental program. So, acceleration, impact force, and displacement values are obtained during the tests. Besides, damage developments of the pipes are also observed to determine the impact resistances of test members. The results are compared to each other and it is stated that while acceleration and impact force values decrease, displacement values increase as the test members approach to collapse damage situation.**

***Keywords*** **– Damage development, measurement devices, pipe sections, test setup.**

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## 1. Introduction

Pipelines are occurred by pipes with different sections and they are in the position of passing different geographic locations. They are not only used for transferring drinking or waste water. They are also used for transferring different materials as petrol and natural gas which are utilized for energy generation. It is important to decide the proper section sizes while designing pipelines. Pipe sections shall minimize the operating and maintenance costs during the economic life of the pipelines. Therefore, environmental conditions, construction methods and technological advancement need to be taken into consideration in the design process. In this way, proper material amounts can be determined to provide the stabilization of the pipelines [1,2].

Development in engineering field changes according to material variety. It is important to know the advantages and the deficiencies of the materials in the project. Environmental factors such as wind, wave, flow, earthquake, geological conditions and temperature have some negative effects on the functions of the pipes. In addition, the pipes are under the risk of potential landslides and rock falls in mountain regions. For this reason, sudden dynamic effects shall also be considered in addition to other loading combinations in the project of the pipelines [3,4].

Impact loading is an example of dynamic loading whose effect is bigger that other load types [5]. Materials and structural members shall also resist impact loads as well as other ones. However, it is not easy to apply impact loading on test members. Since it has been a popular subject to understand the behaviour of materials under impact loading, researchers have developed different test setups recently [6-9]. Low velocity impact loading is applied by these test setups and crack development with damage situations of the test members can be observed in this way [10,11]. On the other hand, similar computer simulations have been performed to compare the experimental and the numerical studies [12-14].

In this paper, an experimental program for galvanized and water filled galvanized pipe sections is performed [15]. A test setup is developed for this purpose. Impact loading as an example of rock falls on pipes is applied by using free falling test apparatus. A constant weight test apparatus is used in the experimental program. The impact loading is applied from 100 cm by a steel hammer whose weight is 12 kg. The tests are continued until the pipes reach failure damage situation where maximum displacement is observed. Acceleration, impact force and displacement values are obtained by measurement devices. The values are converted into diagrams to visually present the results according to damage situations of the test members. Besides, energy capacities are calculated by taking impact force-displacement graphs into consideration. Finally, impact resistances of the pipes are comparatively obtained.

## 2. Experimental part

### *2.1. Measurement devices*

Test setup is developed to perform tests for pipes under impact loading. A test apparatus, accelerometers, a dynamic force sensor, an lvdt and a data logger take part in the test setup. The test apparatus that applies impact loading on test members is the most important part of the test setup. Different masses can be dropped from various heights by this apparatus. The best way to simulate impact effects on test members is to use free falling weight test apparatus. Potential energy is converted to kinetic energy at impact moment. The sizes of the base platform of the apparatus are 1000x1000x200 mm. There are two slides in the apparatus and the distance between the slides is 200 mm. Steel hammer is placed between these slides. In addition, optic photocells are placed on the right slide of the apparatus. Thus, drop times and numbers can be followed by the electronic screen of the test apparatus. To restrain the movement of the test members during tests, steel devices are used to provide support conditions at both ends. The test apparatus is shown in Figure 1.

*Figure 1. Test apparatus*

Steel hammer applies the impact loading on test members. Connection of the hammer to the test apparatus is provided by wheel shaped members. The material of these members is castermid whose mechanical strength value is very high. Although the mass of the hammer can be changed, it is taken constant during free fall tests. Technical drawing of the steel hammer is presented in Figure 2.

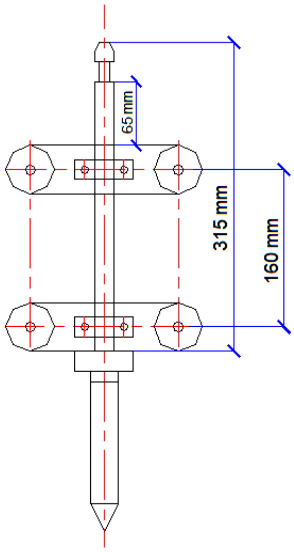



*Figure 2. Drawing of the hammer*

Two accelerometers are symmetrically placed on the test members to measure acceleration values for each drop. Shock accelerometers are used in the experimental program. These accelerometers are produced from piezoelectric material and they have the capacity to measure any vibrations without losing signal quality. They are used to determine the impact behaviour of several materials as well as instant effects during projectile and missile strikes. Accelerometers that are used in the experimental program have ±98000 $m/s^2$ measurement range, ±490000 $m/s^2$ overload limit (shock) and 0.05 $mV(m/s^2)$ sensitivity with a working temperature between -18 and +66 $^oC$. The accelerometers are placed into brass devices to measure reliable values during tests.

A dynamic force sensor that is used in impact and crash tests is placed in the edge part of the steel hammer in the test apparatus. Thereby, the force sensor moves with the hammer to measure impact force values for each drop. Sudden dynamic effects can be accurately measured by this sensor. Big force values in very short time spans can be measured by force sensor without any loss. The dynamic force sensor has 88.96 kN measurement range and 60 kHz upper frequency limit with a working temperature between -54 and +121 $^oC$.

Linear variable differential transformer (lvdt) that is used to measure the displacement values of the pipes during the tests. Lvdt is an electromagnetic convertor that converts the linear mechanical movement of an object to electric signals. It can both give the displacement value and its direction. Since it has a durable inner structure, it can be used in different environmental conditions. Lvdt has 25 mm measurement range, 4-20 mA output signal and ±0.25% linearity with a working temperature between -18 and +66 $^oC$.

The data logger is an electronic device that saves data according to time. It can be used in dynamic applications of civil and earthquake engineering fields. All measured values by accelerometers, dynamic force sensor and lvdt are transferred to data logger by connection cables. Measurement values are collected by data logger very fast. The collected values are converted to computer data. Finally, all the results are transferred from data logger to the computer. The data logger in the experimental program has 138 dB dynamic measurement range, 24 bit adc resolution and 12 vdc power input with a working temperature between -20 and +50 $^oC$.

### *2.2. Methods*

After creating the test setup with necessary measurement devices, impact loading is applied on the pipes. Potential energy is converted to kinetic energy at impact moment. Loss of energy during drop movement is equal to the acquired energy by test member. While drop height is 100 cm, the mass of the steel hammer is 12 kg during tests. Galvanized pipe member in the test setup is presented in Figure 3.

*Figure 3. Test setup*

Measured values are transferred to computer from data logger. Afterwards, the values are converted to acceleration-time, impact force-time and displacement-time graphs by a special software in the computer.

## 3. Test Members

Two types of test members as galvanized and water filled galvanized sections are used in the experimental program. Diameters of the pipe sections are 2", 3" and 4". Test members are divided into two groups as galvanized and water filled galvanized pipe sections. The length of the sections is 100 cm. Preparation of water filled galvanized pipe section is presented in Figure 4.

*Figure 4. Produce of test members*

To provide the fixed support conditions at both ends, strong devices that are produced by steel material having 5x5x50 cm sizes are utilized in the experimental program. Test members are placed to test setup by providing support conditions. Afterwards, measurement devices as accelerometers, force sensor and lvdt are assembled to their places. Accelerometers are symmetrically placed from 25 cm distance of impact point. Force sensor moves with the steel hammer and it measures the impact force when the impact force is applied by the hammer. On the other hand, lvdt is placed to test members by using a lath. In this way, displacement values are obtained for each drop movement of the hammer. The views of a test member are in the test setup seen in Figure 5.

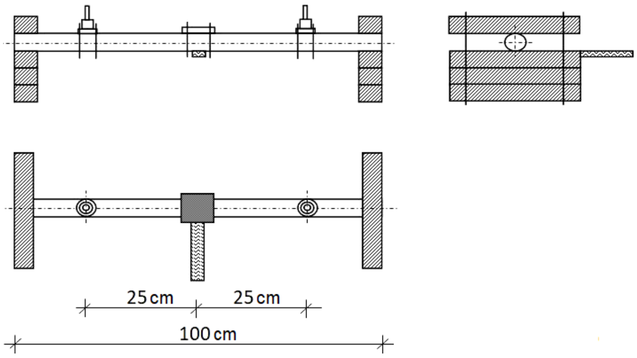



*Figure 5. Front, top and side views of a pipe section*

All measured values are collected by data logger and transferred to the computer. Impact loading is applied on a high strength steel plate that is placed on the middle of the test member. Galvanized pipe with measurement devices is presented in Figure 6.

*Figure 6. Measurement devices on test member*

## 4. Test Results

Acceleration, impact force and displacement values are converted to time dependent graphs by using the software in the computer. Before starting tests, calibration practice is performed as presented in Figure 7. In this way, the number of data for each second is introduced to the software. So, experimental data is determined in a particular way.

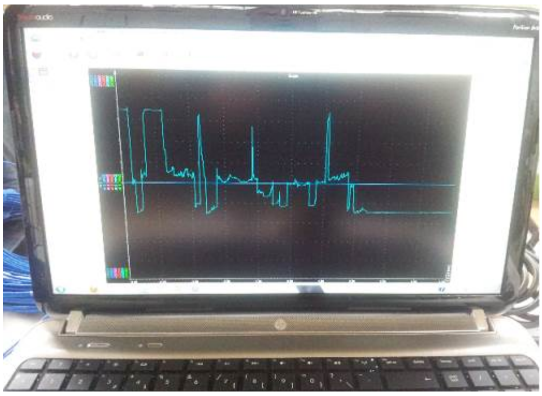


*Figure 7. Calibration practice*

Damages are accumulated around impact point as given in Figure 8. Impact tests are continued until test members reach collapse damage situation where maximum displacements are observed. Therefore, total drop numbers for all test members are determined. In addition; acceleration, displacement and impact force values are obtained for collapse situation.

*Figure 8. Damage during tests*

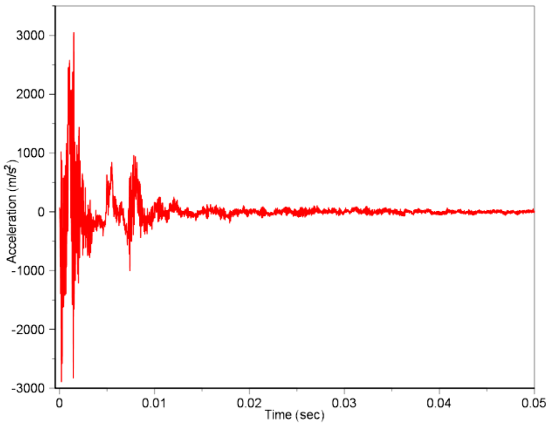
Impact forces are applied by free fall of drop weights during the tests. Locking mechanism of the test setup is utilized. So, rebound movement of the steel hammer is prevented. The tests are performed for one single drop of the hammer.

Since the accelerometers are symmetrically placed from the impact point, measured acceleration values are close to each other. Acceleration-time graphs are designed by taking bigger acceleration values into consideration among two accelerometers.

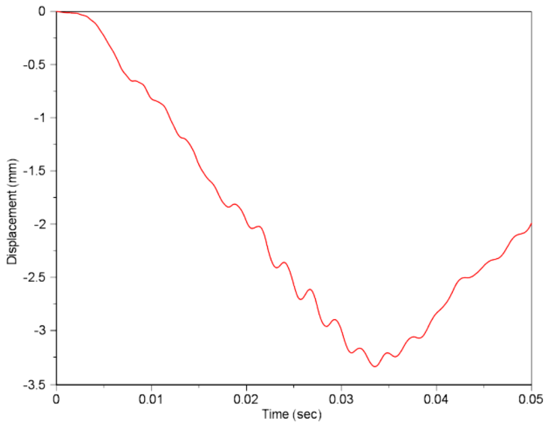
In addition, displacement-time and impact force-time graphs are determined by considering the measured values by lvdt and force sensor respectively.

Impact force-displacement graphs are obtained by considering both impact force-time and impact force-displacement graphs for the same time interval.

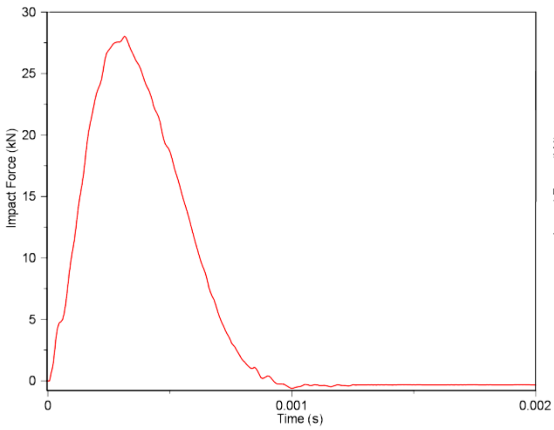
Acceleration-time, displacement-time, impact force-time and impact force-displacement graphs are formed for both galvanized and water filled galvanized pipe sections that are tested in the experimental program. The graphs are presented for the first drop movement of pipes having 2” diameter in the following figures.



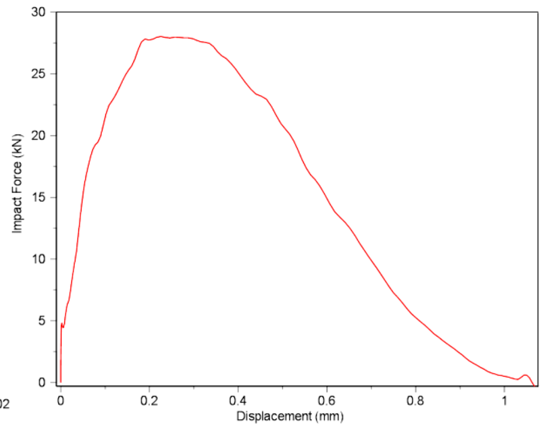

*a) Acceleration-time graph*




*b) Displacement-time graph*

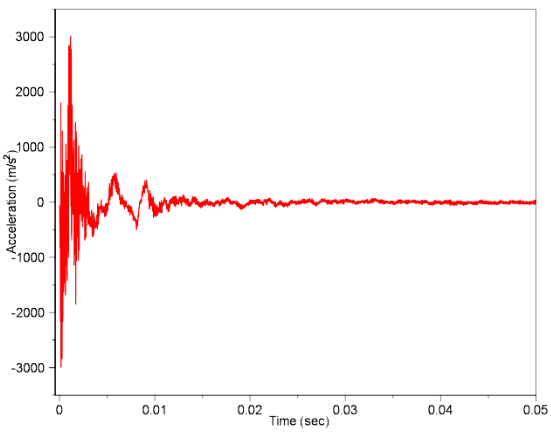



*c) Impact force-time graph*

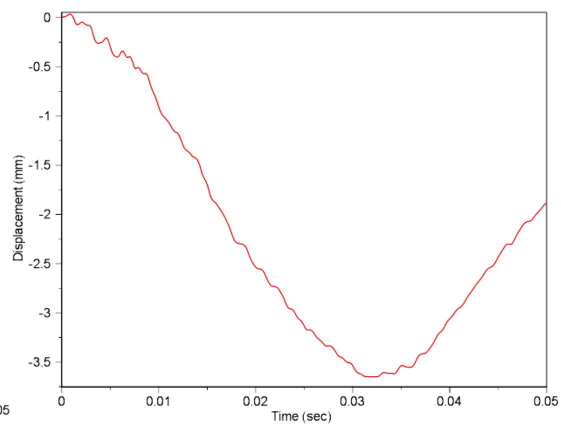



*d) Impact force-displacement graph*

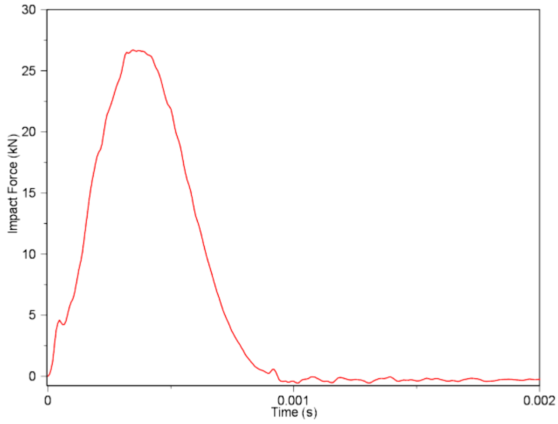
*Figure 9. Graphs for galvanized pipe with 2” diameter*



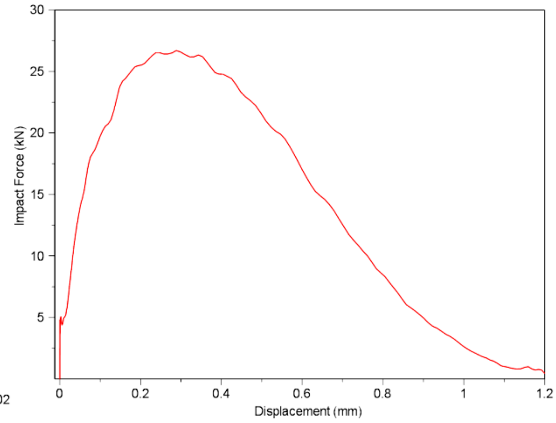

a) *Acceleration-time graph*




b) *Displacement-time graph*




c) *Impact force-time graph*




d) *Impact force-displacement graph*

*Figure 10. Graphs for water filled galvanized pipe with 2" diameter*

Experimental program has been continued until the test members reach collapse damage situation. While non-damaged situation is represented by first drop, collapse situation is marked by final drop in the tables. The maximum displacement value is measured by lvdt in the collapse situation. Measured values for test members according to damage situations are given between Table 1 and 3.

*Table 1. Test values for test members with 2" diameter*

| Test member | Drop | Acceleration ($m/s^2$) | | Max. displacement (mm) | Max. impact force (kN) | Max. energy capacity (j) |
|---|---|---|---|---|---|---|
| | | Min. | Max. | | | |
| Galvanized pipe | First drop | -2891 | 3049 | 3.34 | 28.03 | 15.95 |
| | Final drop | -2253 | 2417 | | | |
| Water filled galvanized pipe | First drop | -2994 | 3008 | 3.65 | 26.71 | 14.74 |
| | Final drop | -2247 | 2388 | | | |

*Table 2. Test values for test members with 3" diameter*

| Test member | Drop | Acceleration ($m/s^2$) | | Max. displacement (mm) | Max. impact force (kN) | Max. energy capacity (j) |
|---|---|---|---|---|---|---|
| | | Min. | Max. | | | |
| Galvanized pipe | First drop | -3317 | 3157 | 2.95 | 31.65 | 17.23 |
| | Final drop | -2468 | 2581 | | | |
| Water filled galvanized pipe | First drop | -3224 | 3286 | 3.11 | 30.14 | 16.87 |
| | Final drop | -2413 | 2462 | | | |

*Table 3. Test values for test members with 4" diameter*

| Test member | Drop | Acceleration ($m/s^2$) | | Max. displacement (mm) | Max. impact force (kN) | Max. energy capacity (j) |
|---|---|---|---|---|---|---|
| | | Min. | Max. | | | |
| Galvanized pipe | First drop | -3869 | 3577 | 2.28 | 36.20 | 19.74 |
| | Final drop | -3107 | 3261 | | | |
| Water filled galvanized pipe | First drop | -3626 | 3754 | 2.43 | 35.37 | 18.31 |
| | Final drop | -3144 | 3181 | | | |

Each drop time is recorded by optic photocells in the test setup. Both drop times and the drop numbers can be seen on the electronic screen after each drop movement of the hammer. Total drop numbers of the test members are given in Table 4.

*Table 4. Graphs for water filled galvanized pipe with 2" diameter*

| Test member | Total drop number |
|---|---|
| 2" galvanized pipe | 8 |
| 2" water filled galvanized pipe | 6 |
| 3" galvanized pipe | 12 |
| 3" water filled galvanized pipe | 9 |
| 4" galvanized pipe | 20 |
| 4" water filled galvanized pipe | 16 |

## 5. Conclusion

Pipelines are structural systems that transfer the necessary material from one point to another one. They are used to transfer a variety of materials, especially natural gas, petrol and water by passing different geographic conditions. Pipelines are designed against both static and dynamic loads with operating loads as internal gas and liquid pressure. In addition, the pipelines are under the effect of sudden impact incidents as landslides and rock falls. Therefore, different test setups are designed to investigate the impact effects.

In the scope of this study, both galvanized and water filled galvanized pipe sections having 2", 3" and 4" diameter values are tested under impact effect. For this purpose, a well instrumented experimental program is performed in a laboratory. Free falling impact weights are applied on the test members. Besides, measurement devices as accelerometers, lvdt and force sensor are used during the tests.

Test values are obtained by measurement devices and transferred to data logger by connection cables. Finally, the values are collected in the computer and converted into acceleration-time, displacement-time, impact force-time and impact force-displacement graphs. In this way, the behavior of the test members is investigated under impact effect.

Acceleration values are measured by two accelerometers that are symmetrically placed from 250 mm distance of impact point. When the acceleration values are investigated, the biggest values are obtained from the galvanized pipe with 4" diameter. It is stated that acceleration values increase as the diameter values get bigger. On the other hand, the values decrease from the first drop to the final drop where collapse situation is observed.

Displacement values are measured by an lvdt in the test setup. While minimum displacement value is obtained from the galvanized pipe with 4" diameter, the maximum displacement value is measured from the water filled galvanized pipe having 2" diameter value. Displacement values become bigger as the damages occur in the test members. So, maximum displacements are observed for the final drop movement of the steel hammer for all pipe sections.

Impact forces are determined by dynamic force sensor that is placed in the edge part of the steel hammer. In this way, the impact force values are obtained for each drop movement. When the results are investigated among the test members, it is observed that measured impact forces decrease from the first drop to the final drop movement due to damage development. Maximum value is obtained from the 4" galvanized pipe.

Energy capacity of the test members is calculated by considering the area under the curve of impact force-displacement graphs. Energy capacity values increase as the diameter of pipe sections get bigger values. On the other hand, damage development has negative effects on the energy capacity of the test members.

When the total drop numbers of test members are investigated, it is determined that maximum drop numbers are observed for 4" galvanized pipe. It means that, this test member reached collapse damage situation at the latest among all. More drop movement of steel hammer is required as the diameter values of test members increases.

Finally, this study can be improved by investigating various types of pipe sections under different dynamic loading cases. In addition, damage development can be followed by a fast and high capacity camera during the tests. Computer analysis may also give an idea about the behavior of the test members.

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