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IMPACT RESPONSE ANALYSIS OF RETAINING WALL UNDER FALLING WEIGHT IMPACT LOAD

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By

Abdul Qadir Bhatti*[1,2], Guilio Ventura[1], Asim Bashir[2], Muhammad Yousaf Anwar[2], Ihsan Ullah Shah

Abstract

Natural disasters range from falling weight, avalanches and accidental loads to earthquakes, floods and tornadoes. These infrastructural damages can be mitigated by performing a rational impact response analysis considering these loads. Retaining walls / rockfall protections are constructed along the highways in mountainous areas. If space between road and edge of cliff is not sufficient, thinner reinforced concrete (RC) retaining walls with pile foundation are used. In Japan, retaining wall attached to a two layer absorbing system comprising expanded polystyrene (EPS) and RC layer, connected to steel piles is developed for such restricted locations. In order to formulate a practical design methodology for such impact resistant retaining walls, the applicability of method was confirmed by conducting field tests using prototype retaining wall. This study focuses on finite element (FE). Analysis of a retaining wall under falling weight impact load and establishes a rational 3D FE analysis method, to predict accurately, the response of an impact resistant retaining wall under falling weight impact load. For the purpose, a multi-use FE software "LS-DYNA" code is used.

Key words: Finite element analysis, Impact analysis, Retaining wall performance, LS-DYNA

1. Introduction

Older structures were mostly designed only for static loads but recently there has been a growing awareness to design some to resist both dynamic impact and static loads. An accidental impact load can be caused by mishaps as well as accidents stemming from transportation or natural disasters. In addition, structural components can be subjected to a range of deliberate impact loads such as military activity or terrorist attacks. In order to establish a rational impact resistance design procedure for RC retaining wall based not only on allowable stress design but also on ultimate state design and/or performance based design method, impact resistant capacity and/or maximum input energy for RC retaining wall must be clearly estimated. However in this research maximum input impact force will be numerically estimated by means of three dimensional elasto-plastic finite element method (FEM) for RC retaining wall (having three layers of absorbing system including RC retaining wall, EPS layer and RC layer) under falling heavy weight by using software LS-DYNA Code.

There are a number of ways of predicting how an impact load will affect a concrete structure, some of which may be impractical or expensive but because there have been significant developments in technology, numerical techniques rather than experimental approaches have become popular methods for developing detailed responses. Furthermore, numerical modeling for reinforced concrete structures that are subjected to impact loads is a design concept that has not yet been realistically fully developed. Thus, the finite element

* Corresponding Author and Membership No. 4389 of Pakistan Engineering Congress (***bhatti-nit@nust.edu.pk*** or ***draqbhatti@gmail.com***)

1 Department of Structural Geotechnical and Building Engineering (DISEG), Politecnico di Torino, Italy

2 School of Civil and Environmental Engineering (SCEE) ,National University of Sciences & Technology, Islamabad, Pakistan

package LS-DYNA compared was undertaken to examine the behavior of RC retaining walls subjected to impact loading.

2. Research Significance

Following are the key research objectives which are dealt in this thesis.

1. To establish an analytical technique that can simulate the impact behavior of RC retaining walls.
2. To provide guide lines to the structural engineers on this important aspect.
3. To compare the effects of using different yield criteria in the numerical analysis.

The following postulates enunciate the significance of this research study:

1. The main advantage is to establish an analytical technique for design/construction of RC retaining wall.
2. Minimize occurrence of damages due to such accidents by incorporating this design technique.
3. Suggests a viable solution to study the impact behavior of falling heavy rocks on RC retaining walls by using LS-DYNA code.

3. Methodology

The finite element models were developed to replicate the behavior of RC retaining walls subjected to a falling weight impact test. In order to achieve the objectives described above, the following tasks were performed:

1. Gathering of relevant available research on the use of composite grids for concrete reinforcement to establish the need for new and innovative methods for the analysis/design of reinforced concrete retaining walls.
2. Evaluation of the current finite element analysis techniques to model reinforced concrete.
3. Development of finite element models (with different falling heights) to evaluate the potential for simulating different failure modes.
4. Selection of material model formulations and material properties for concrete and reinforcement to model the correct constitutive behavior of the RC retaining walls.
5. Comparison of the dynamic characteristics and failure modes of the finite element simulations with available experimental data.
6. Development of recommendations for further research based on the results of the finite element simulations and comparison with experimental data, in order to provide a more reliable and effective numerical model to predict the correct capacity and failure mode of the retaining walls.

4. Finite Element Based Software – LS DYNA

There are different finite elements modeling programs used for modeling dynamic events such as rock fall, dynamic compaction using ABACUS, ANSYS, DYNA-3D, LS-DYNA, Particle Flow Code (PFC) etc. Most of them have different constitutive models related to soil and rock.

For the present investigation LS-DYNA is chosen for the rock fall impact modeling on cushion materials. LS-DYNA is a general purpose finite element code for analyzing the large deformation dynamic response of structures including structures coupled with fluids. The main solution methodology is based on explicit time integration. The analysis can be easily applied for stress analysis of structures subjected to a variety of impact loading. Main purpose of numerical modeling in the present study is to model the rock fall impact on cushion materials at prototype energy levels in the order of million joules. A variety of element formulations are available in LS-DYNA for each element type. It is specifically suitable for crash analysis involving high velocity impact events similar to rock impact on cushion materials and it is easy to model a rock impact event with different variations of influencing parameters and to measure stresses induced in the gallery. More details about the program can be found in LS-DYNA users manual (LS-DYNA, 2003).

The 2007 version of LS-DYNA used in this research provides theory and user manuals (Hallquist, 2006), numerous material models, and various contact options useful for concrete impact and penetration analysis. The code includes an advanced and separate pre and post processor, called LS-PrePost, for efficient input creation and output management.

5. Experimental Setup

The experiments were performed in Japan by a team of experts in which Dr A.Q. Bhatti was a part. Experimental set up shown in Figure 1. A heavy weight that imitates the falling rock was lifted up through the detaching device with the help of crawler crane and dropped from prescribed height freely on to the retaining wall. The mass of the heavy weight used in the experiment was 5,000 Kg as it causes big impact energy.

Figure-1. Experimental Setup

Two types of retaining walls were used in the experiment; one with two buffer layers and one without any buffer layer. The dimensions of the retaining wall are shown in Figure 2. A

5,000 kg heavy-weight was used as falling weight. In this research the maximum impact velocity of heavy-weight for the first test was set as 3.5 m/sec for retaining wall with buffer layers. EPS is used as main buffer layer. EPS is a lightweight cellular plastic material consisting of small spherical shaped particles containing about 98% of air. It also shows a good compressive strength and it hardens after repeated impact loading. It is assumed that the damage of the concrete of the retaining wall made of RC structure is negligible as compared to buffer material at the heavy weight collision position in the actual experiment. The velocity of impact was increased gradually from 3.5 m/sec to 5.0 and 7.0 m/sec to attempt good use of the efficiency of the examination block and the experiment was repeated.

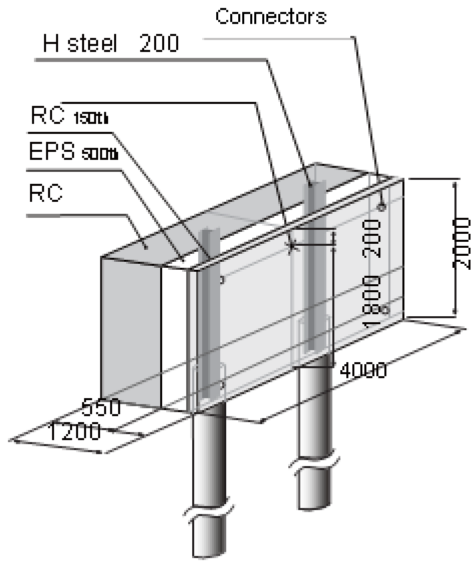

Figure-2. General Dimensions of RC Retaining wall

The impact velocity for retaining wall without buffer layer is fixed as 5.0 m/sec. These four experimental cases are shown in Table-1.

Table-1. Experimental Case List

Experimental Case	Buffer Layers	Mass of heavy weight (Kg)	Impact Velocity (m/sec)	Concrete strength (MPa)
Case 1-1	Yes	5,000	3.5	24
Case 1-2	Yes		5.0	
Case 1-3	Yes		7.0	
Case 1-4	No		5.0	

6. Numerical FE Model

The re-bar arrangement of the RC retaining wall is shown in Figure-3 and FE numerical analysis model is shown in Figure-4 (a and b) for cases with and without buffer layers consisting of EPS block and RC layer, respectively. Only half of RC retaining wall model and falling heavy-weight were modeled with FE meshes considering symmetrical axis. Six and/or eight node solid elements were applied for all of these FE models except axial re-bars. Total number of nodes and elements of the RC retaining wall model with two absorbing systems are 56,933 and 62,978 and are 49,964 and 54,436 without buffer structure, respectively. Numerical analysis models were precisely formed for each component based on the dimensions of the RC retaining wall model used in the real structure. Falling weight is a hemispherical cylinder having a diameter of 1.0 m and weight of 5 ton.

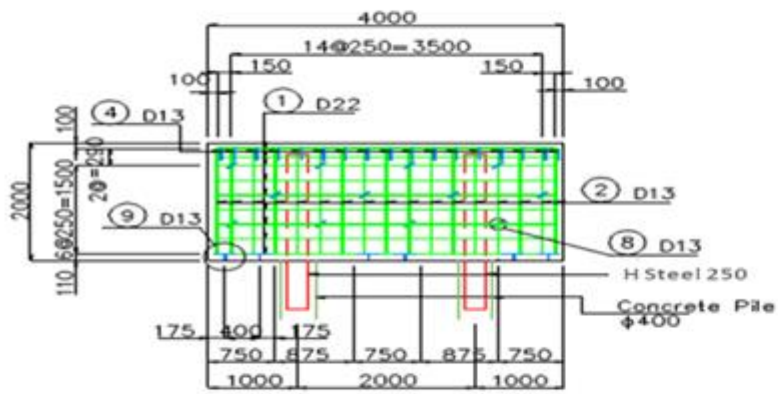

Figure-3. Rebar arrangement of RC Wall Body

Contact surface is defined between striking face of heavy-weight and the side surface of the absorbing system, in which sliding with contact and separation can be considered in this contact surface applied . All nodes between concrete and re-bar were assumed to be perfectly bonded with each other. Impact force is numerically surcharged against the RC retaining wall due to adding a predetermined impact velocity to all nodes of falling heavy-weight which is set on the surface of absorbing system. Impact response analysis for RC retaining wall model was performed up to 300 ms from the beginning of impact. The time increment for numerical analysis is almost equal to 0.2 ms.

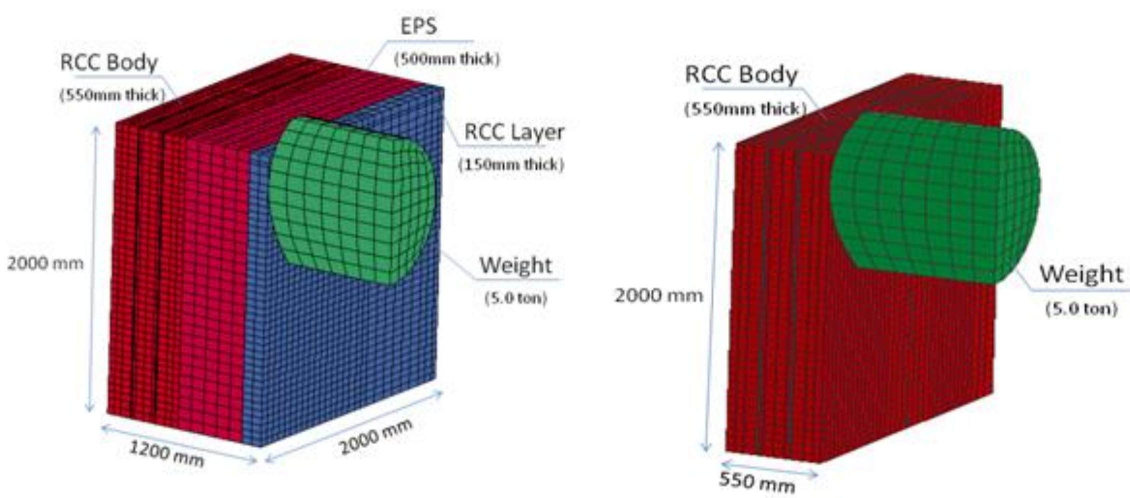

Figure-4. Meshed FE models in LS DYNA (Left) Case applying EPS and RC layer (Right) Case without Cushion Layers

7. Modeling of Materials

Figure-5 shows the stress-strain relations for each material: concrete, re-bar and EPS block. Neither strain rate effects of all materials nor softening phenomenon of the post peak of concrete were considered for this elasto-plastic impact response analysis. The constitutive law for each material characteristic is outlined below:

Concrete

Stress-strain relation of concrete was assumed by using a bilinear model in compression side and a cut-off model in tension side as shown in Figure 5 (a) namely,

1. Yielding stress is equal to compressive strength f'c
2. Compressive strain at the yielding point is equal to 1500 µ strain
3. The tensile stress is steeply decreased to zero when an applied pressure reaches the ultimate tensile strength and its value is 1/10th of the compressive yielding stress

Both Von Mises and Drucker Prager yield criteria were applied as the yielding condition in concrete. LS-DYNA material model MAT_SOIL_AND_FOAM_FAILURE was used to model the concrete elements.

Rebars

For main rebar and shear rebar, an elasto-plastic model with isotropic hardening was applied as shown in Figure 5 (b). Plastic hardening modulus H was assumed as 1 per cent of elastic modulus, Es. Yielding condition was judged based on Von Mises yield criterion. LS-DYNA material model MAT_ PLASTIC_ KINEMATIC was used to model main and shears rebar.

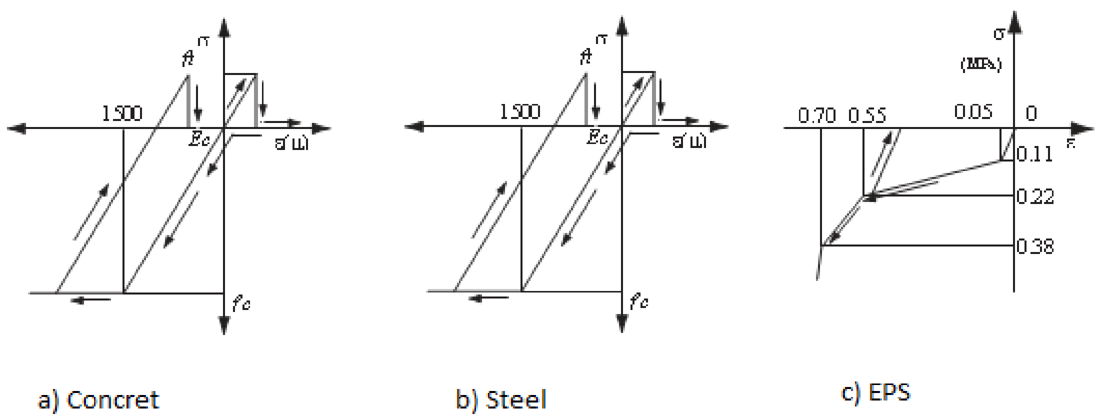

Figure-5. Stress strain relationships of material constitutive models

Falling Heavy Weight

The other elements (falling steel weight, anchor plates and bottom layers) were modeled as elastic body based on experimental observations.

Expanded Polystyrene (EPS) Block

Based on the concept as shown in Figure 5 (c), it is assumed that the EPS layer will one-dimensionally behave against a collision of a falling rock in an effective area. The stress-strain relation of the EPS layer is multi-linearly modeled based on the curve obtained from the static loading test with 10 mm/min loading speed. The maximum design strain of the EPS layer is limited to 0.55. LS-DYNA material model MAT_CRUSHABLE_FOAM was used to model the EPS block.

Use of Damping Constant

In order to accurately simulate impact response characteristics of the models, a damping constant was considered and set up at 5% for horizontal natural frequency.

8. Comparison of FE Model Results and Experimental Results

The contactless laser displacement sensor measures the horizontal displacement in horizontal direction is installed at rear surface of the RC retaining wall body. Load cells for the impact stress measurement also installed shown in Figure 6.

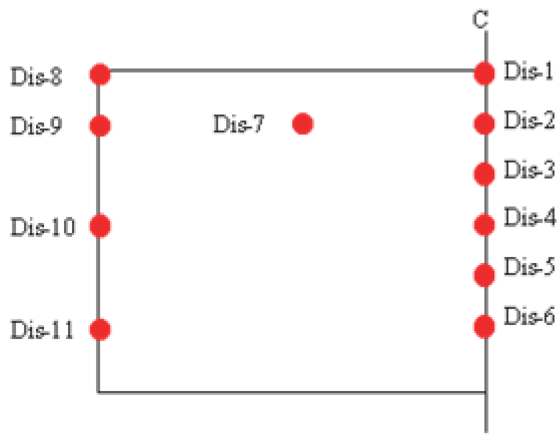

Figure-6. Measurement Position

Time Histories of Displacement Waveform

The numerical analysis results for time histories of displacements at eleven displacement measurement positions as shown in figure 4.6 are presented in graphical form for two types of yield criteria i.e. Von Mises and Drucker Prager. Figure 7 compares the individual displacement waveform at each measurement position against three velocities i.e. 3.5 m/sec, 5.0 m/sec and 7.0 m/sec for the case where two-layer buffer structure is installed, while using Von Mises and Drucker Prager Yield criteria, respectively.

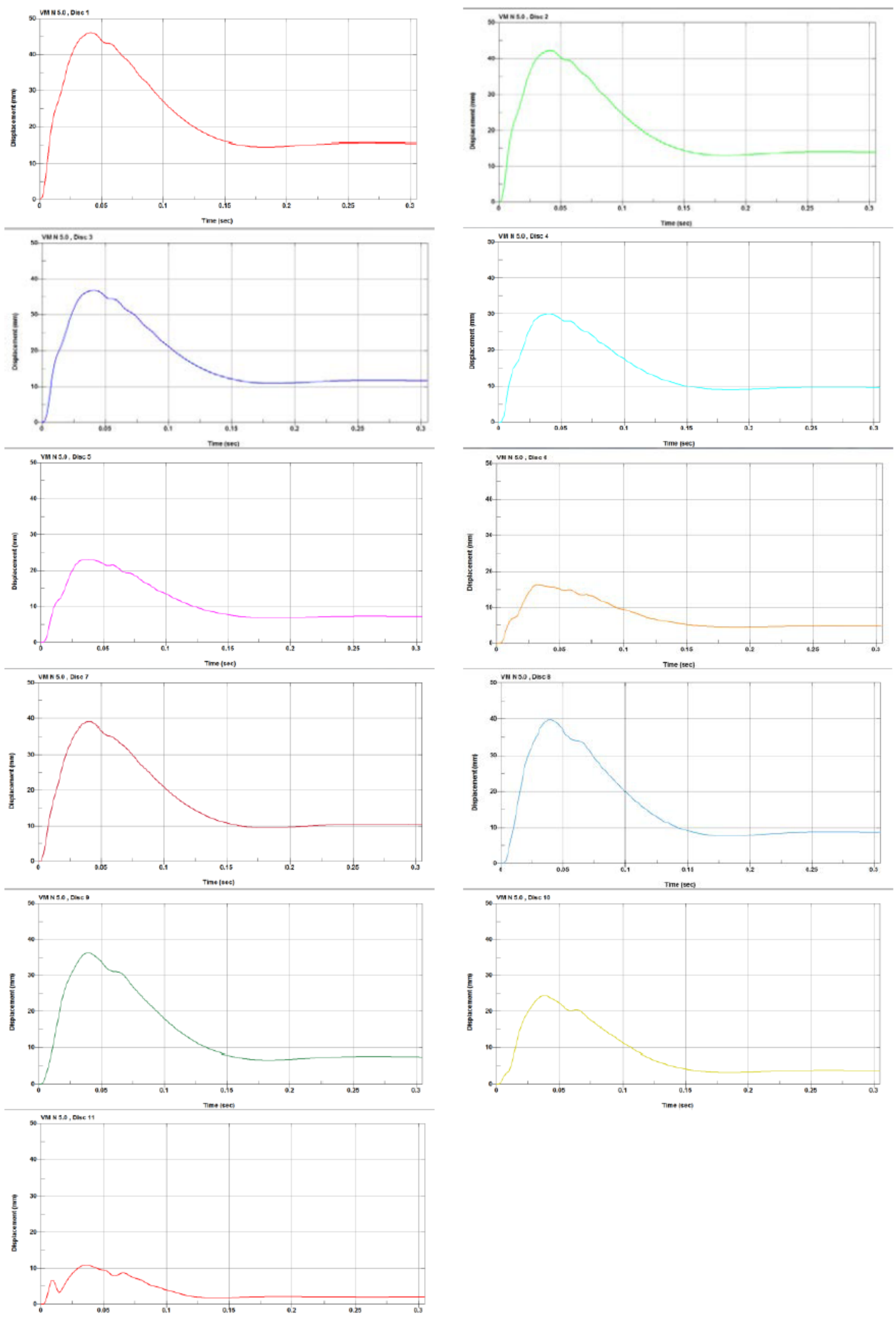

Figure-7. Displacements for different setups of the retaining wall

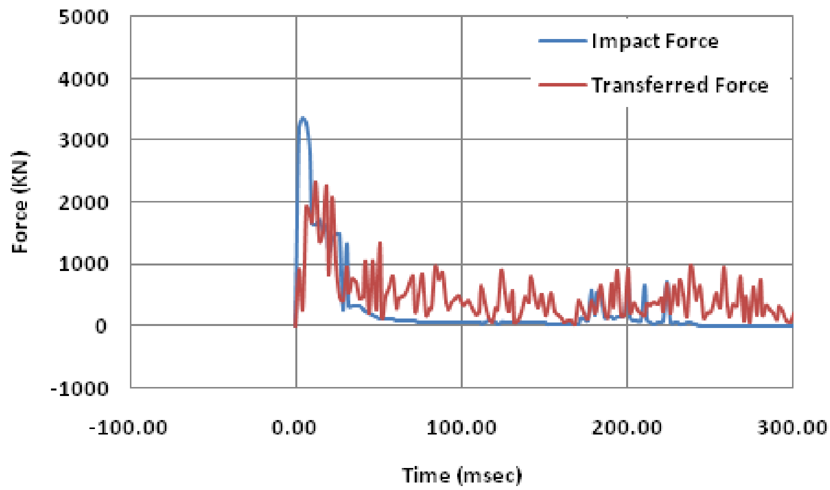

Figure-8. Impact Force vs Transferred Force

From these figures, following results are obtained:

1. It is observed that displacement waveforms configuration is almost similar for all measurement positions, with a difference in maximum value.
2. In the case of a two-layer buffer structure the displacement waveform increases gradually after the collision.
3. There is very little or no residual displacement remains in the system.
4. With an increase of a collision velocity, maximum displacement increases.
5. While in case when no buffer structure is installed, displacement increases rapidly after the weight is collided and some quantity of residual displacement remains, which is not generated mostly in other cases.
6. In addition, it is also observed while focusing on the Dis-2, Dis-7 and Dis-9, that for a two-layer buffer structure, the retaining wall displaces as a whole.
7. In case of retaining wall without buffer structure, it can be seen that the displacements have decreased significantly with increasing distance from the impact position, suggesting that the shape of the retaining wall body has changed.
8. The effect of distance from the impact position can be seen very clearly.
9. Wave configurations from the beginning of impact through the maximum value are almost similar to each other, irrespective of yield criteria.
10. It is observed that in case when buffer structure is installed, there is no considerable difference in maximum displacement by changing the yield criteria, however a little increase in residual displacement is observed in case wherein Drucker Prager yield criteria is used. In the case when no buffer structure is used, the difference is, however, significantly increases, both for maximum and residual displacements, in case of Drucker Prager yield criterion.
11. It is seen that the vibration period after reaching maximum amplitude and the damping characteristics are different in cases retaining wall with and without buffer layers.

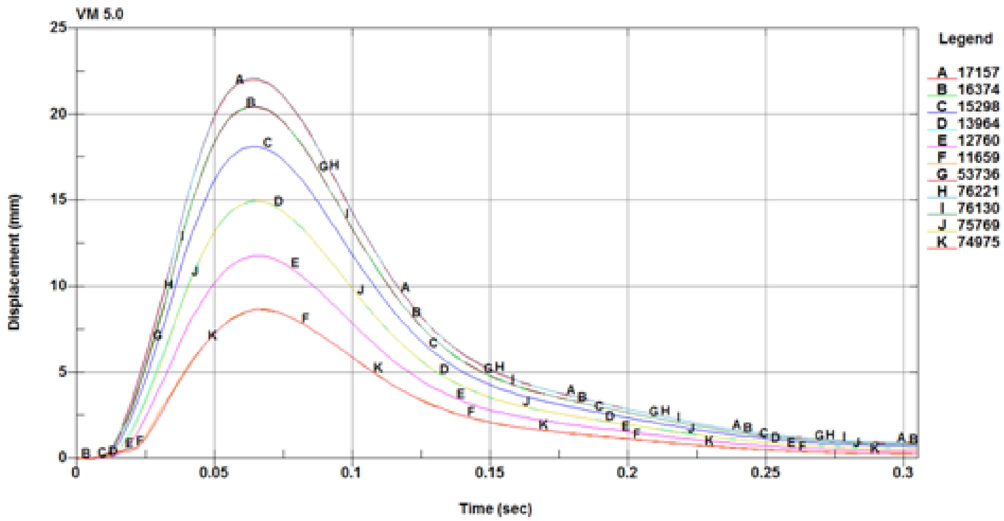

Figure-9. Time vs Displacements for Different Velocities

9. Conclusions

Following conclusions can be made by comparing retaining wall with and without buffer layers.

1. Impact force due to weight is reduced.
2. The maximum response value of output displacement decreases to almost half.
3. In case of retaining wall with buffer layers, since the wall moves as a whole due to impact, so the overall deformation of the retaining wall can be reduced.
4. Transmitted impact force is decreased to almost two third of impact force by applying buffer layers.
5. The RC retaining wall with buffer layers vibrates with smaller residual displacement as compared to wall without buffer layers.

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