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IMPACT OF A SEMIRIGID EXPLOSIVE MISSILE ON A CONCRETE BARRIER

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1.0 ABSTRACT

Explosions are short duration dynamic events that generate pressure waves which propagate radially from the source in space, exciting dynamic response in the structures that are encountered in their path. The pressures acting on the affected surfaces are impulsive loads that impart significant amount of energy which introduces damage-causing vibrations in the structure. Chemical explosions are based on the energy released from the rapid oxidation of fuel elements. Gas-chemical explosions produce large dynamic loads that are much greater than the original design loads of many structures**.** The specific energy of combustion of a hydrocarbon fuel is very high (46000 kJ/kg for propane, compared to 4520 kJ/kg for TNT).

This paper examines the effects of impact of a steel, semi-rigid missile made of Steel4340 as provided in Ansys work bench 2022-R1 with explosive TNT as provided in Ansys work bench 2022-R1 packed inside the missile container, hitting on a concrete box type structure. The concrete box resembles the 3D protective cover of any target, and the missile considered here represents missiles fired from any missile launcher . The study reported here assumes for simplicity that the missiles impact on the barrier is perpendicular to the plane of the barrier and explosion takes place before the missile reaches the concrete barrier. The barrier is assumed to be made of reinforced concrete M35 grade as provided in Ansys work bench2022-R1 material modelling library , a commonly used material for this purpose due to its structural stiffness and ductility for absorbing the effect of impact and explosion. The failure model are evaluated in Brittle Crack Concrete(B.C),Concrete Damaged Plasticity (CDPL) and RHT model using Ansys Work bench 2022R1 .Based on the analysis results , material stresses of concrete grade 35Mpa of Ansys explicit WB. Rebar and semirigid missile material was considered as Steel4340 grade once again an Explicit Dynamics material from Ansys WB. The study evaluates the reason for failure of concrete elements in the impact zone and analyses the reasons why steel reinforcement did not fail.

Here in this paper, the concrete will be subjected to two different types of impacts. The first one is impact of high incident overpressure acting on the concrete surface due to detonation of an explosiveTNT from a distance of 3.7m from the RCC wall. The second one is the impact of a rigid missile flying at a high velocity and consequental damage in concrete surface . The twain effect of an impact and detonation of a flying rigid missile with explosive packed inside can create minor damage (scabbing) or a full perforation on a concrete surface depending on the velocity ,weight of the missile and quantity of explosive charge.

2. INTRODUCTION:

2.1 Impact and Blast model discussed in this paper are as follows.

In Ansys work bench 2022/R, the author has developed three models in Explicit Dynamics to analyse the effect of impact of a Rigid Steel Missile packed with explosive hitting on a RCC Box with the following example cases.

Case-1 : RCCBox-1E Case-2: RCCBox-2G Case3: RCC Box-2H .

2.1.1 *Case-1:RCCBox-1E*

(a) The model in case-1 consists of a Reinforced concrete box (Lagrange reference frame)of outer dimension 20mx20mx20m with wall thickness 10cm contains 82 nos 36mmdia rebar(Steel4340) placed at the center of the concrete wall grade M35(Explicit) at equal spacing along the entire length of all the four walls.

(b) The RCC box is filled with air (Eulerian reference frame) in atmospheric pressure.

(c) 3.5m long 2m dia cylindrical missile in steel 4340 was developed in Lagrange reference frame. To pack TNT in the missile ,a cavity was made of length 1.0 m and 1.5m dia which had been curved out in the back end of the cylindrical missile body. This missile was placed at a distance of 0.2m from the outer face of RCC Box and flying towards RCC box at a constant speed of 300m/sec .
(d) Explosive TNT was modelled in a circular thick disk form with diameter 1.5m and length 1.0m as per Ansys WB material model, and was modelled in Eulerian reference frame and packed inside the cavity of the missile at the back. The detonation time was considered to be 0. Sec that is when the front end of the missile is at a distance of 0.2 m from the face of the RCC Box. Detonation point was assumed as 3m from the face of the RCC Box .
(e) Lastly, all the above parts were enveloped by a boundary air module of size 30mx30mx30m.
Both TNT and Air was meshed as Eulerian. The velocity of the missile was constant as 300m/sec constant for 125 steps in analysis setting. The reason for detonation at the back end was to see the dynamic effect of air blast on the vertical face of the RCC Box walls.To do this to happen,the detonator was placed at the back side of the missile and detonation time was regulated as 0sec so that the blast wave pressure reaches the box wall almost same time instant the missile hits the outer surface of the RCC Box wall.basic geometrical dimension, number of component parts are all same with exception like variation of impact velocities starting with 300m/sec in case-1 ,750m/sec in case-2 and 1875m/sec in case-3.

2.1.2 *Case-2 : : RCCBox-2G*

All the details of case-1 being same with exception of Impact velocity which is changed to 750m/sec .

2.1.3 *Case-3: RCCBox -2H*

All the details of case-1 being same with exception of missile being placed at a distance of 0.3m ,thickness of reinforced concrete wall as 0.15m, Impact velocity is 1875m/sec.

2.2 OBJECTIVE OF THIS PAPER *:*

The author by analyzing the above three cases wanted to investigate how the blasting phenomenon along with impact creates a deadly combination which leads to failure of concrete barrier .Towards that goal,he had extracted the following results from the Ansys workbench and discussed them in subsequent chapters.
a.Total deformation at specified time instant and max value during the entire process of impact.
b. Equivalent von mises stress values also at all the time instants mapped and maximum values.
c. Equivalent Elastic Strain at all time history for Concrete and Steel rebar.
d. Max Principal and Shear Stresses at all time points mapped.
e. A graph developing the RHT Elastic, Fracture and Residual Failure Surfaces
f.Whether the concrete in RCC Box is getting perforated due to Impact and explosive air thrust.
To create the blast effect on the vertical box wall of the model ,the location of the explosive TNT was put at the back end of the missile of length 3.5 and at height from ground as 10m and detonation is starting at 0 sec so that we get stress time history even before the missile impacts the wall.This type of type of airburst exist, which is Surface Burst .This occurs when detonation takes place close to Ground or on Ground. In this case of Blast Wave propagation, the incident and reflected waves from box wall are merged near the detonation point to create a combined reflected wave. The created wave is-hemispherical.
The Incident pressure –time equation after it reaches the structure is expressed as below
$P(t) = P_{so}[1-(t-t_a)/t_d]\exp[-\alpha(t-t_a)/t_d]$ for $t >= t_a$.

2.3 LITERATURE SURVEY:

The physics behind the blast load analysis had been experimented and numerically solved since last 30 years by many researchers. The development of a new concrete model for hydrocodes started at Ernst-MachInstitute early 1997 with the perspective of the later dissertation by Riedel [9], under the direction of Prof. Dr. Thoma and close support by Prof. Dr. Hiermaier. The initials 'RHT' of this development

team later formed the characteristic abbreviation for the model. At that time substantial knowledge on different aspects of the mechanical behavior of concrete was available. Yet, the overlapping disciplines of static strength descriptions, rate dependent strength and shock behavior were not consistently combined to cover with one model approach the range of dynamic applications accessible through hydrocode simulations.[9]
Earlier since 1985 Lots of Study on development of surface blast wave were done by U.S. Army Armament Research, Developmentand Engineering Center, Dover, NJ (1986).
The following papers were published by the author in Smirt 21-24 on the subject of Blast Load Analysis on Structures above ground as well as underground.
1.“**Dynamic Behaviour of Reinforced Concrete Cylindrical Structure with Hemispherical Dome under Blast Loading” Div5 paper ID 236** ***Transactions,SMIRT 21,611November,2011 NewDelhi India*** .
2.The author along with few other Co—authors **Dr. Nishikant Vaidya, P.E, Dr. Umesh Dayal from M/s Paul C. Rizzo Associates, Inc., Pittsburgh, PA, USA** published 2nd paper
“Response Of Underground Structures Subject To Blast Loading Under Ground” inSmirt-22 Div-5.
3. **The two papers published in Smirt-24 Busan, Korea - August 20-25, 2017 Division IV**
a. Vibration Response In Pile Foundation Embedded In Soil Due To Underground Explosion.
Mrigendra Nath Ray1, Rohan Belhe2, Nishikant R. Vaidya3, and Mustafa K. Ozkan3
b. Missile Impact On Reinforced Concrete Barrier Slab Using Various Failure Models
By Mrigendra Nath Ray1, Shivam Srivastava2, Nishikant R. Vaidya3, and Eddie Guerra.

3. ANALYSIS OF RESULTS:

Nine figures 1-9 are presented which shows Von Mises stress time history on Concrete and Steel due to Blast effect due to detonation of explosive and due to Impact of the Missile on the RCC Box wall.

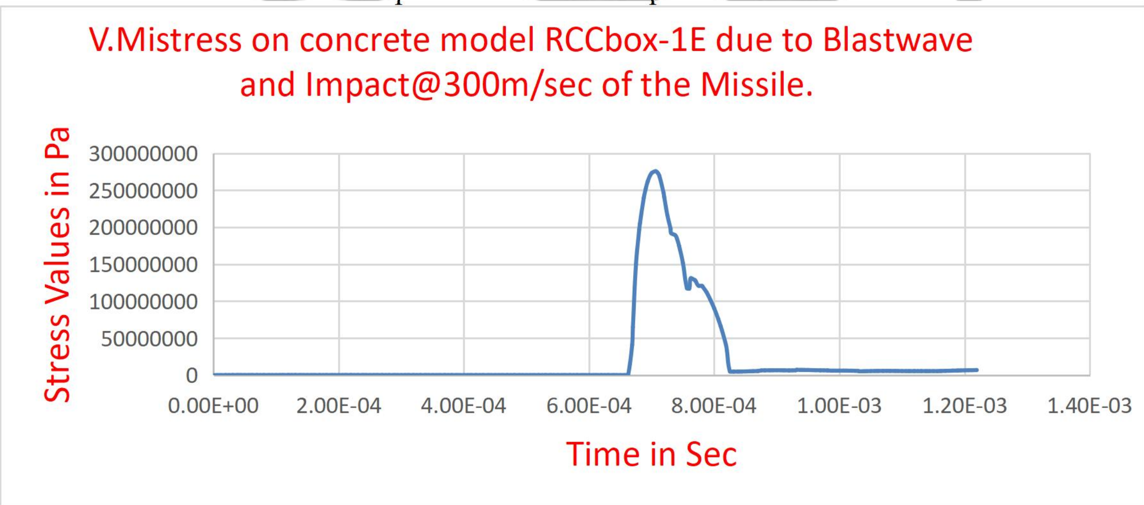


Fig-1 V.M Stress on Concrete Box-1E Due to Blast wave and Impact

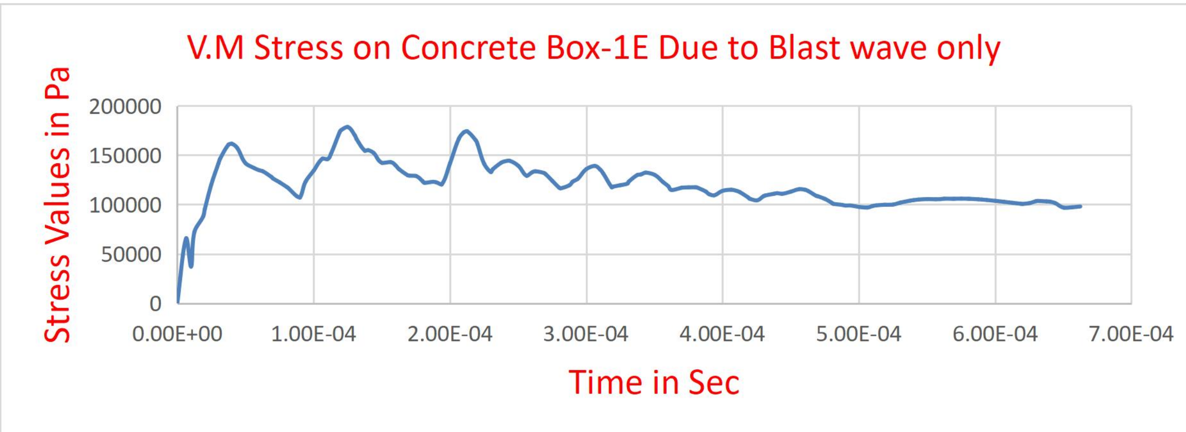


Fig-2 V.M Stress on Concrete Box-1E Due to Blast wave

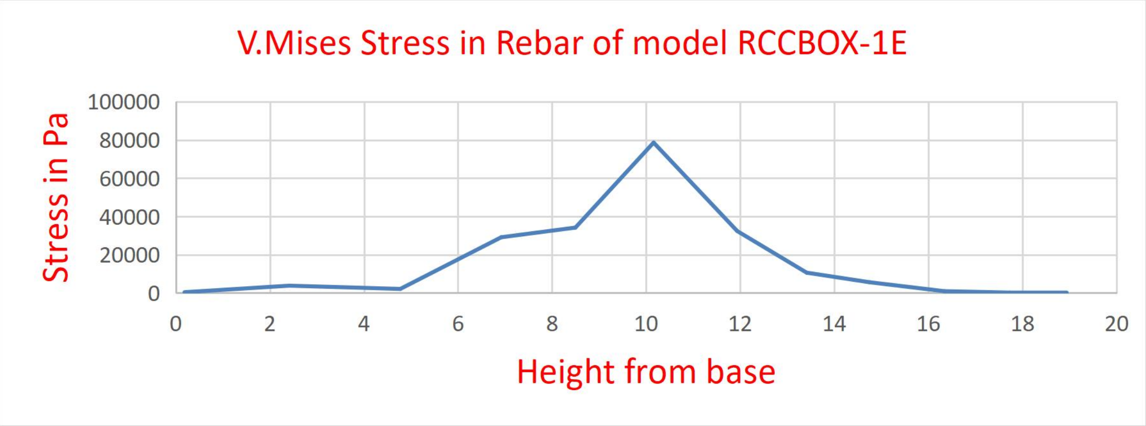


Fig- 3 V.M Stress mapping along height of Wall

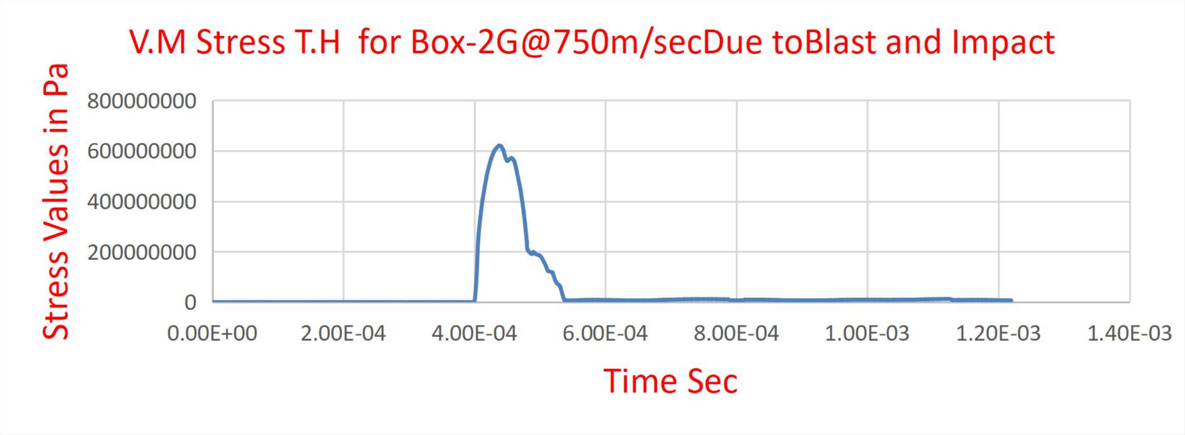


Fig- 4 Von Mises Stress T.H due to Blast wave and Impact.

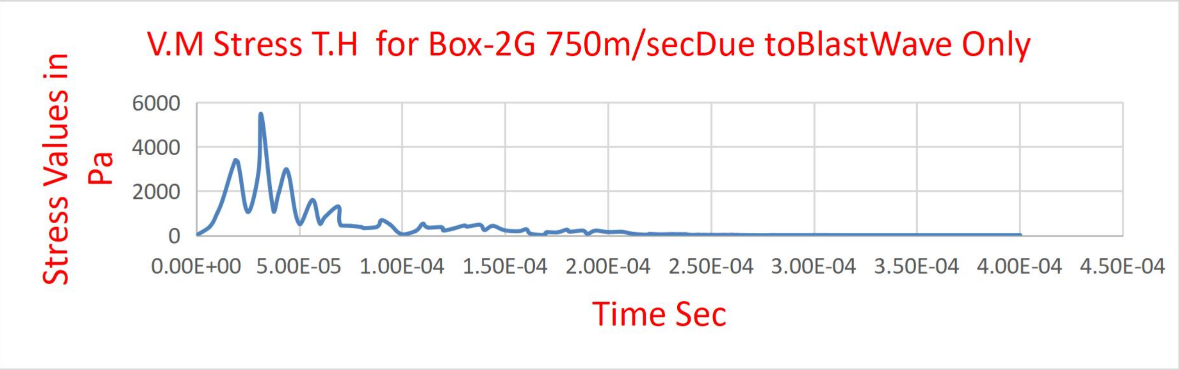


Fig- 5 V.M Stress in Concrete due to Blast wave only ModelBox- 2G

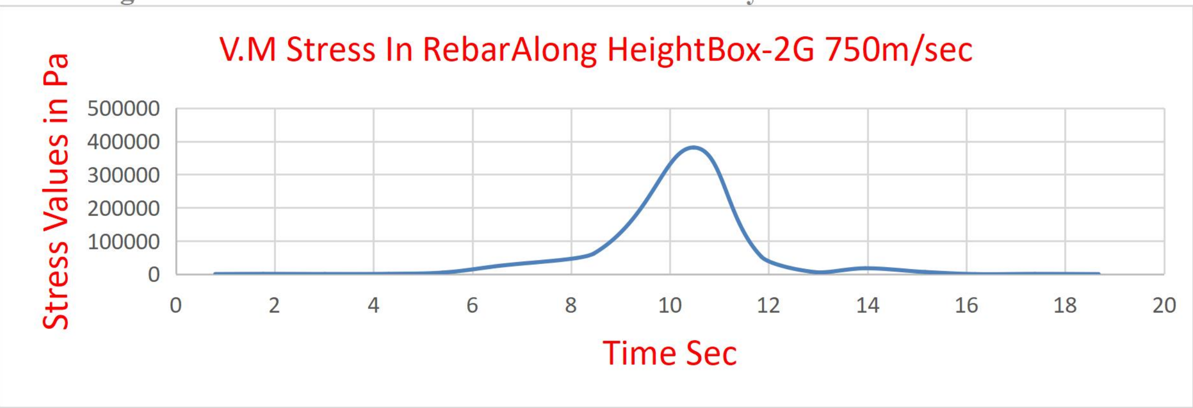


Fig-6 Stress mapping along height from Base

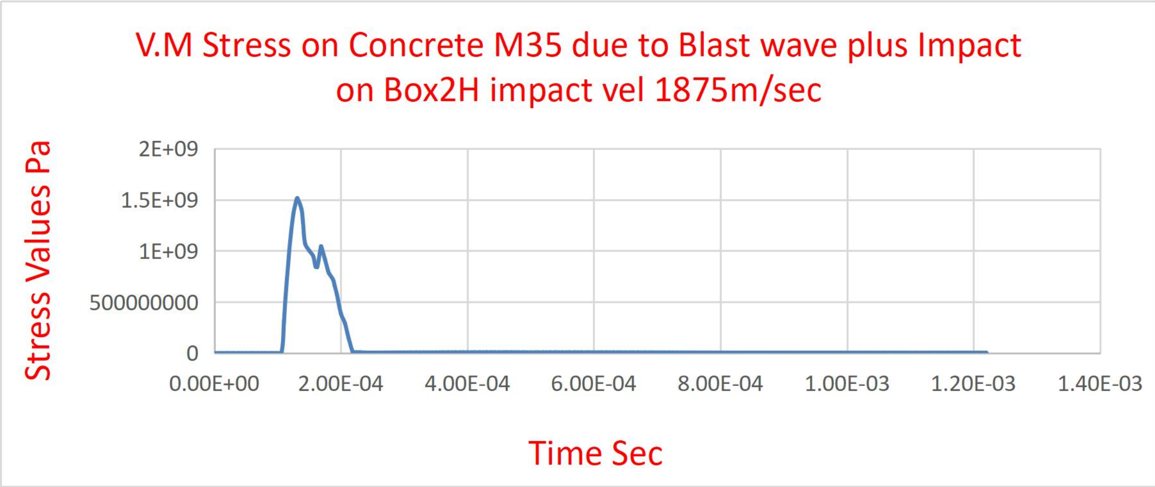


Fig-7 V.M Stress on Concrete M35 impact vel 1875m/sec

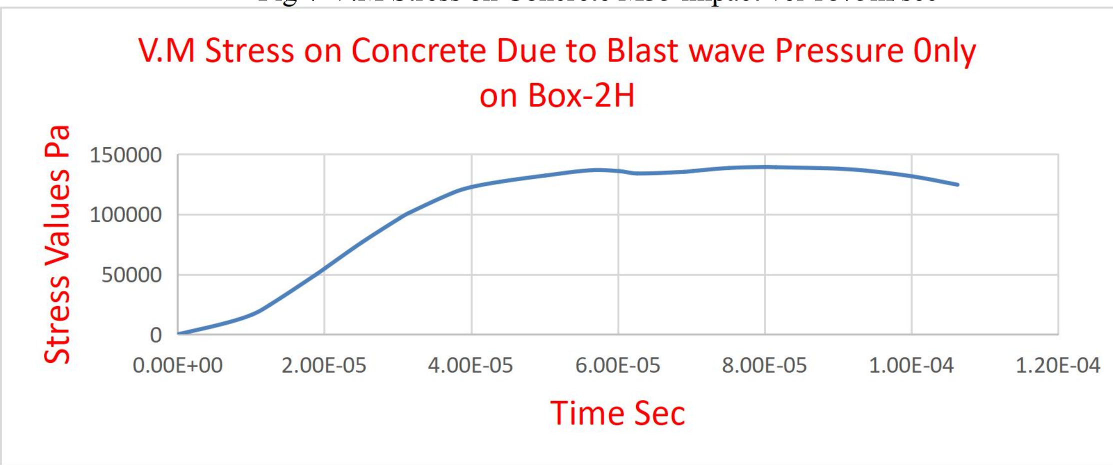


Fig-8 V.M Stress on Concrete Due to Blast wave Pressure 0nly

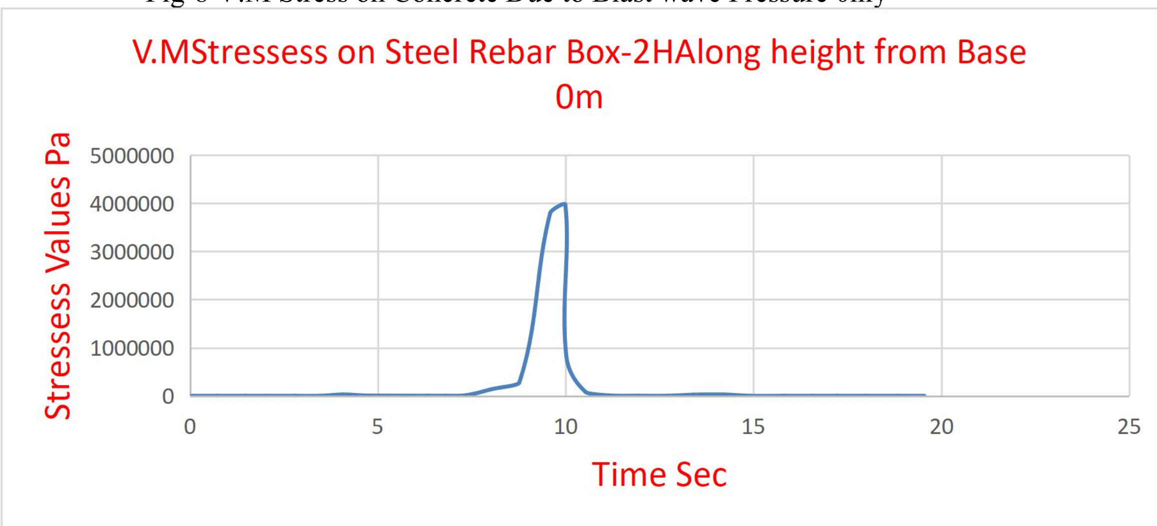


Fig-9 V.M Stress In RebarAlong HeightBox-2H 1850m/sec.

By looking at the Fig-1,4 and 7, we find that in the component part Concrete Box,the stress in concrete has exceeded the ultimate compressive strength 35E+06 Pa almost immediately to a value after hitting the concrete box wall by the missile at time Instant 6.63E-04 ,4.0E-04 and 1E-04 Sec in three cases. Before that, the stress in concrete rose from 0Pa at start 0 sec and rose up to 1.615E+05 Pa at 4.40E-05Sec time instant due to Blast wave Pressure on the wall (Fig-2) and thereafter the stressing pattern went up and down gradually with few up peaks and valley due to reflection from the Box wall to a value

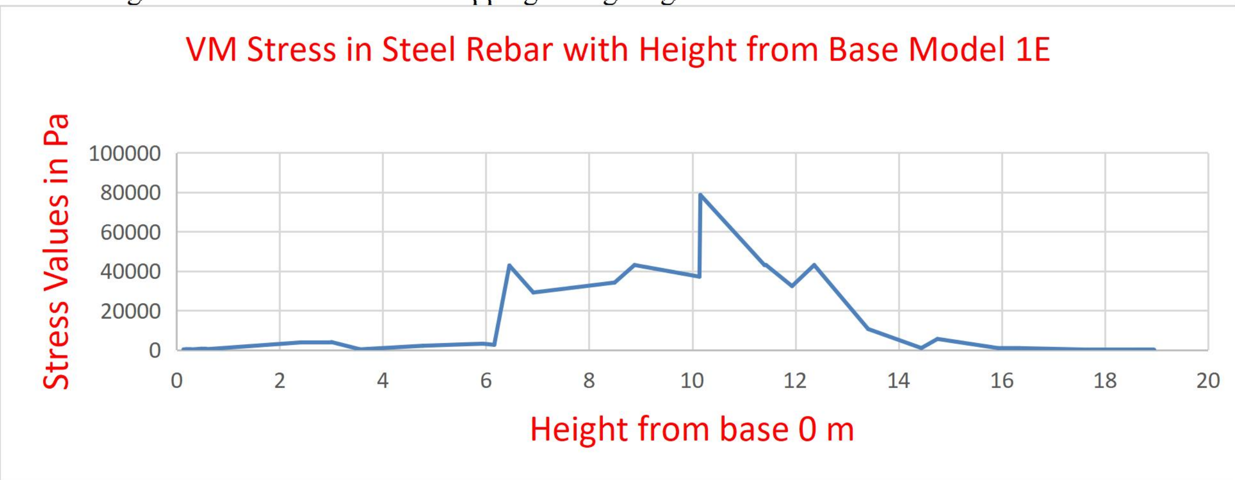
100000Pa at 5E-004 sec. After this time instant the V.M Stress in Concrete wall started rising sharply due to the effect of Missile Impact at 300m/sec (in fig-1).Similar trend can be observed from Fig-4&5 when the impact velocity is 750m/sec in model RCCBox-2G and Fig-7&8 for impact velocity 1875M/Sec in model RCC Box 2H .

Due to this impact there is failure and erosion of concrete finite elements but the penetration could not damage the steel rebars even within the zone of maximum impact as per Von-Mises Stress Values mapped in Steel rebars (fig-3,6&9) as it could not exceed the yield strength of steel4340 material 7.92E+08 Pa as per Steel Material4340 data from AnsysWB. The maximum V.M stress value in steel was mapped as 78575 Pa in (Fig-3),381,140Pa in (Fig-6) and 39,76,100 Pa in (Fig-9) which are far less than the above yield strength as per Johnson-Cook model.

Even by developing one more model RCCBox-2F, similar to model of case-1 RCCBox-1E with change in Rebar material from Steel4340 to Structural Steel whose yield strength (Tension) is 250E+06 Pa and change in rebar dia from 36mm to 20 mm with other parameters remaining same,the V.M Stress mapping for rebars for time history up to 6E-04sec showed stress in Steel as 68286Pa.The above time history data was even extrapolated to the end time 1.25E-03sec to estimate

The stress value 98000Pa at end time 1.25E-03 sec.

Fig- 10 V.M Stress&Strain mapping along height of Wall



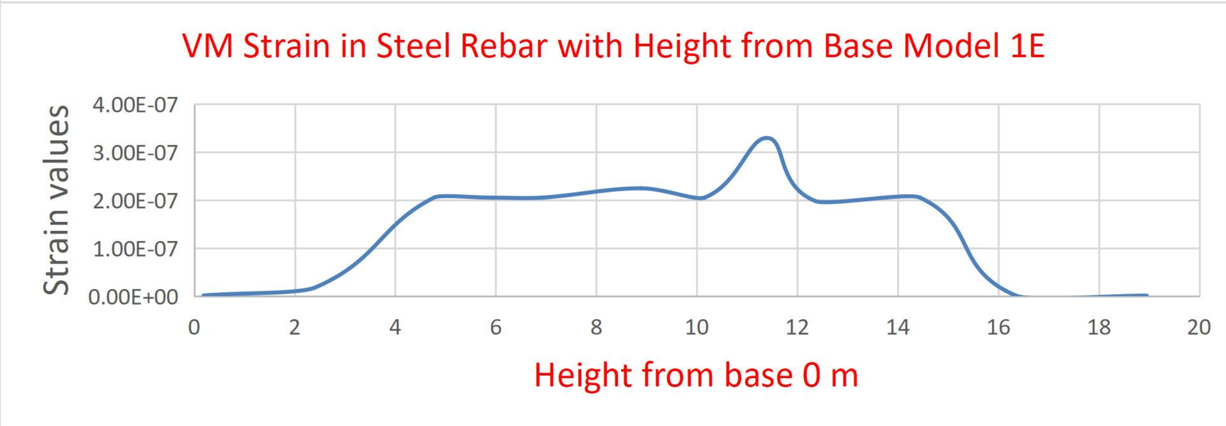


Fig -11 V.M Strain Mapping along Height from Base 0m

From the result files of AnsysWB,we map the V.Mises Elastic Stress and strain values on rebar at 10m above the base which eventually will be the area where max impact of missile will be felt.

Stress Value= 78575 Pa at height 10.157m Yield Stress of Steel4340 =7.92E+08Pa

Strain Value = 2.06E-07 at height 10.157m E=2G(1+Nu)Pa Nu=0.2 G=8.18E+10Pa

Using these data's we arrive Mod of Elasticity =2x(8.18E+10)x1.2 =1.96E+11 Pa

yield tensile strain in embedded reinforcement as per Indian Standard BIS 456-2000 is as below.

Yield StrainЄy $= \frac{fy}{1.15Esteel} + 0.002$ where fy = characteristic strength of steel.and

Esteel =modulus of elasticity of steel. =2.0E+11Pa For Steel4340 fy=7.92E+08Pa

Єy = 1.81E-03 +0.002 =0.00181+0.002=0.00381

whereas the mapped strain in steel is much lower thereby eradicating all possibilities of yielding of steel at this impact velocity 300m/sec.

3.1 VARIOUS FAILURE MODELS :

It is generally accepted that concrete exhibits two primary modes of behavior:

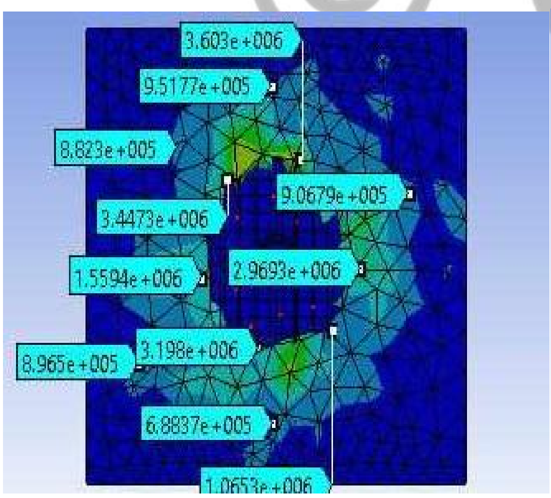
a. A brittle mode, in which micro cracking gradually transforms into macro cracking, with highly localized deformation. This failure model is called as Brittle Crack failure mode(**BCMode of Failure**) .

b. A ductile mode, in which microcracks develop uniformly through the specimen, leading to non-localized deformations. This failure model is called as Concrete Damaged Plasticity model(**CDPMode of Failure**) mode.

c. In addition to the above failure models which have been in use for the last 30 years a new failure model based on concept of Shear failure surface in concrete originally developed by Riedel-Hiermaier-Thoma .The Riedel-Hiermaier-Thoma (**RHT) concrete model**, is a coupled damage-viscoplasticity model, developed by WarnerRiedel and his associates and is readily available to all users in the form of a commercial hydrocode AUTODYN which can be used by Ansys workbench users easily. The Uniqueness of this model is that porosity of concrete is considered in the Equation of State (EOS) while compaction of concrete goes on due to hydraullic pressure as well as diveatric stress being applied.

3.1.1 *Brittle Crack Failure Model Of Concrete* .

A brittle cracking phenomenon is defined when one or more local direct cracking strain at a material point exceeds the failure strain of that material and all the stress components are set to zero.The failed element is removed from the mesh on failure. From the V.M stress output picture(fig-12&13) it is clearly seen that the missile has damaged the concrete by punching which is a clear sign of BC mode of failure. Further It is justified by the fact that the area outside the impact zone exhibitsV.M Stress in undamaged Concrete wall face remains lower than the ultimate tensile strength of Concrete35 which is equal to 0.7xRoot fck where fck=35E+06Pa and ft=4.14E+06Pa.



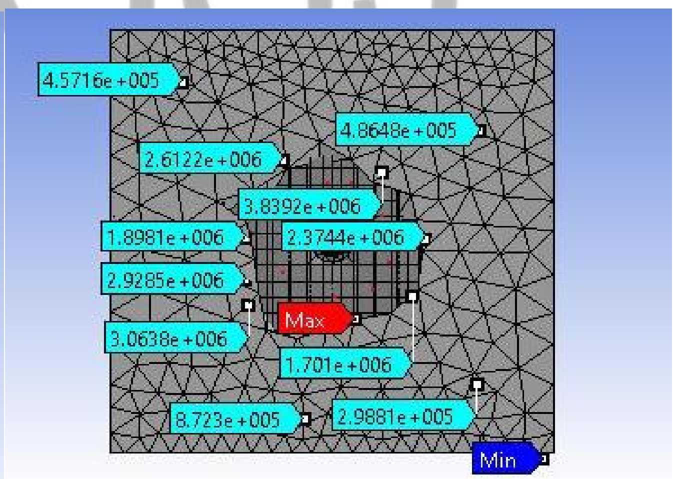


Fig-12 Brittle Mode of FailureBox-1EonV.MStress Fig-13Brittle Mode ofFailureBox-1G onV.M Stress

3.1.2 *Concrete Damaged Plasticity Model*

Concrete damage plasticity material model is a constitutive model used for the analysis of concrete structures subjected to static or dynamic loads and is based on a combination of theory of plasticity and damage mechanics theory (Grassel, Xenos, Nystrom, Rempling, & Gylltoft, 2013).Here in this paper the input for concrete35 is Ec=5000Sqroot (fck) as per BIS 456 (Bureau of Indian Standards) Code of practice for plain and Reinforced concrete . The suggested yield strain value is 0.002 and ultimate value is 0.0035 as per the above code.

Fck for the three caess=35E+06Pa therefore Initial Modulus of Elasticity of Concrete=29580E+06Pa =2.96E+10Pa.

Also we have AnsysWB results for various Stress-Strain state of Concrete35 ,Rebar Steel4340and Missile body made up Steel4340 for 3 cases as explained above. The author has tried to use the Stress-Strain results for Concrete35 only that is derived in Analysis for a time span of 1.25E-03 sec for all 3 cases. The Principal Stress -Strain time history data is presented below in graphical form which will used for further explaining the Concrete Damage Plasticity model behaviour .

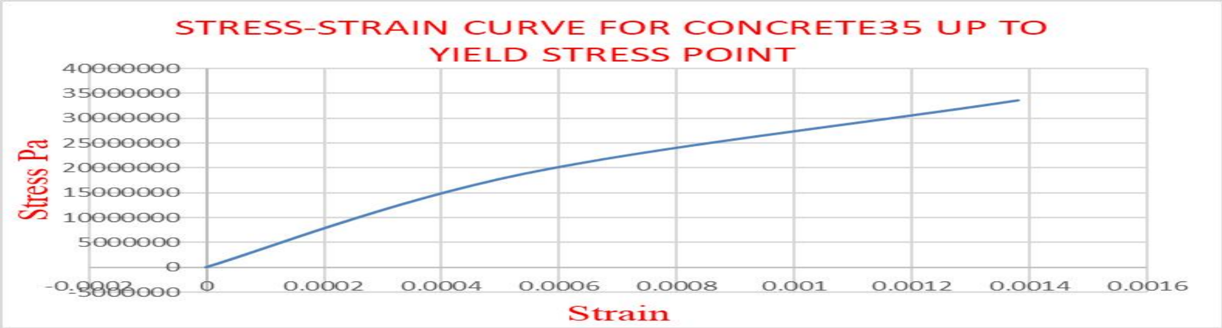


Fig-14

Now if we try to pick the Strain data from the graph at Ultimate Stress point 35E+06Pa as the time history data at yield strain point 0.002 could not be mapped in the analysis results inspite of 294 total time points taken .The next strain point was 0.0046979 and stress mapped was 89.417E+06Pa. So by extrapolating up to the ultimate stress value 40E+06 Pa, the fare assessment of strain value is 0.0016. This way Ec =(40E+06/0.0016) =2.5E+10Pa in place of unstressed modulus of Elasticity of Concrete35 Eo =2.96E+10 Pa earlier calculated based on Indian Concrete Code BIS 456-2000.

Damage of a solid body can be defined as degradation phenomenon in material properties such as stiffness, strength and anisotropy. If the damage is defined by stiffness degradation, the elastic stiffness can be written using stiffness degradation parameter as (Lee J. , 1996) …[8] as E= (1-d)Eo so degradation parameter d works out to be =0.1554 for one stress point beyond ultimate stress zone of concrete.If we pick another Stress Point beyond Ultimate in Fig-15 as below.

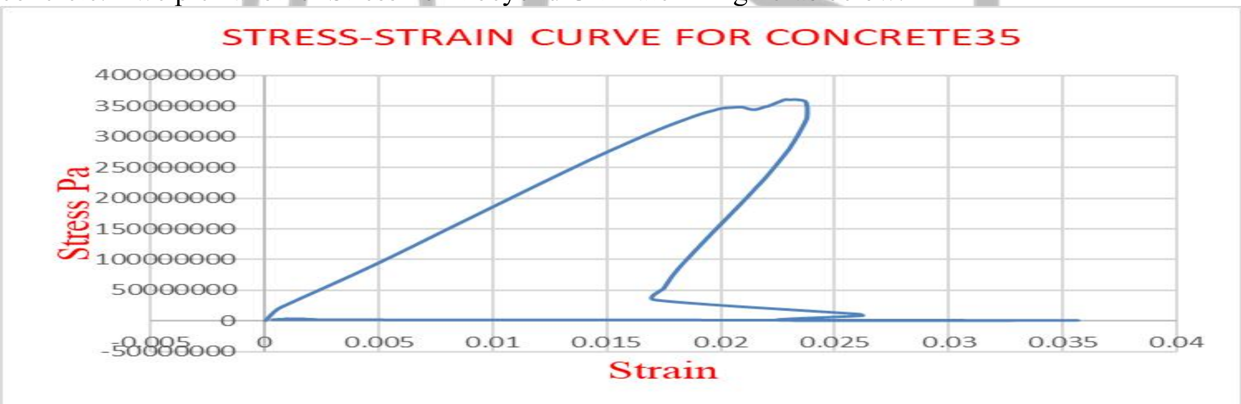


Fig-15

Going on to another case-2 model RCCBox-2G

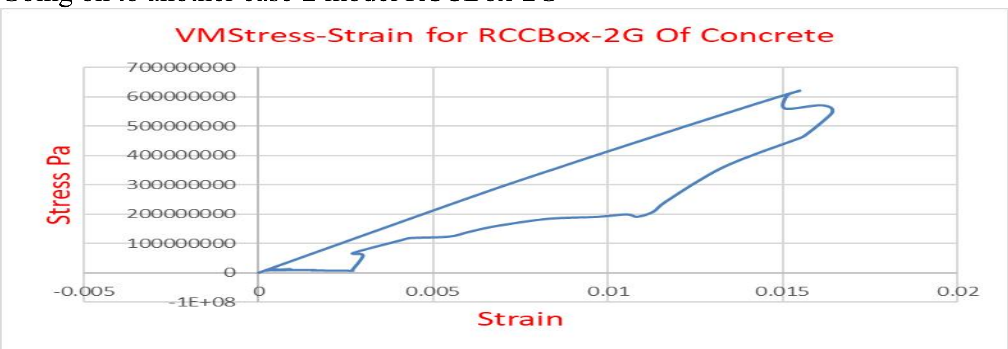


Fig-16

E =311350000Pa/0.0172 =1.81E+10 Pa Eo =2.96E+10 Pa So 1-d =0.611 d=0.389 so it is clear that the damage index is increasing as the missile is continuing penetration till .

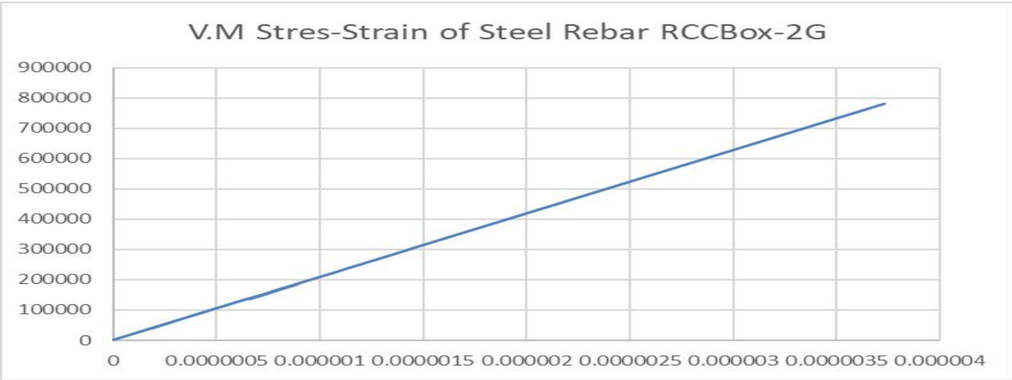


Fig-17

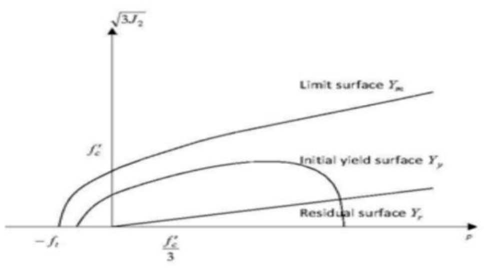
After seeing the V.Mises Stress- Strain Curve Fig-17 for Steel Reinforcement Bar for case-2 RCCBox-2G ,we find a perfect stress-strain curve with Eo (Initial Modulus of Elasticity) value calculated from graph came to 2.06278E+11 thereby confirming no penetration through steel.

3.1.3 *RHT Model of State of Stress:*

The RHT strength model contains three limit surfaces in stress space which considers pressure, triaxiality and strain rate. The three surfaces respectively describe the elastic limit *Y*el, failure *Y*fail, and residual shear strength *Y*res of the damaged concrete under confined conditions.Here also ,development of a RHT Model depends on actual testing work done with firing mechanism of an experimental missile on to concrete targets. Besides, stress and strain data are mapped using electronic strain gauges which can record time history of strains.In this paper, the author is using all the results of the above three cases numerically solved using Explicit Dynamics analysis approach in Ansys workbench .Basically, the author will show how best the results of the numerical analysis can used to satisfy the RHT Strength model.

The author refers the following Technical Report published by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 titled as **Survey of Four Damage Models for Concrete written by** Rebecca M. Brannon and Seubpong Leelavanichkul [6] for guidence in explaining various parameters ,methodology to derive the 3 limit surfaces namely

a. Limit Surface Yfail which is the failure Stress boundary b. Initial Yield Surface and c. Residual Shear Surface Yres.



where

$$r_f = \begin{cases} \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^{\alpha} & : \; p > f_c', \text{ with } \dot{\varepsilon}_0 = 30\times10^{-6}\ \text{s}^{-1} \\ \left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)^{\beta} & : \; p < f_c', \text{ with } \dot{\varepsilon}_0 = 3\times10^{-6}\ \text{s}^{-1}, \end{cases}$$

a_1 = Initial slope of failure surface,
a_2 = Pressure dependence of failure surface,
P_{spall} = Spall strength,
p = Pressure,
α = Material constant,
β = Material constant.

Fig-18 Failure surfaces

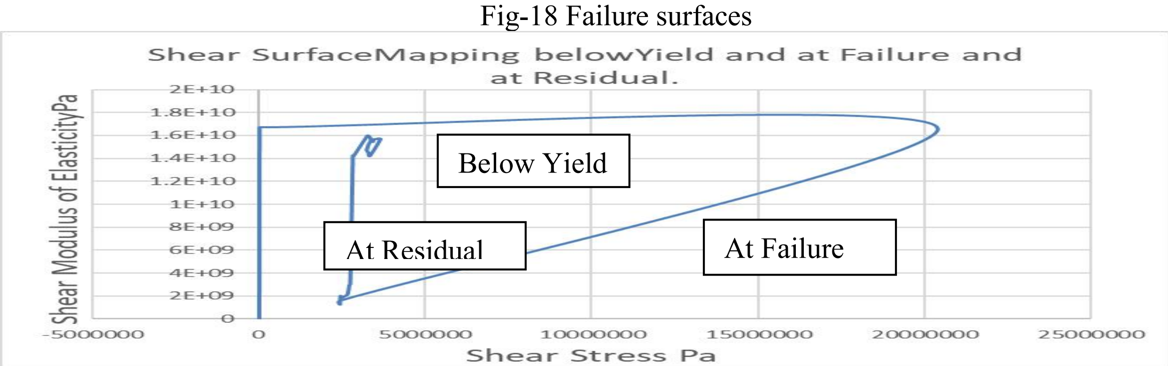


Fig-19

The above graph Fig-19 was developed to pottery the basic concept of the above failure surfaces shown in Fig-18. in RHT failure model of Concrete. Further attempt was made to develop a composite failure surface using the data of Model RCCBox-1E.
Taking 294 data from the 3 Max.Normal stress Time History results Nx ,Ny and Nz obtained from Ansys WB for modelRCC Box-1E we calculated 294 hydrostatic pressure p data set=(Nx+Ny+Nz)/3. Then 294 2nd Stress invariants J2 are calculated as =1/3(Nx-Ny)^2. Thereafter 294 Sqroot of (3J2) is calculated from the earlier step. Then SQRoot(3J2) as ordinate and Hydrostatic Pr as Abscissa a Initial Yield Shear Surface is drawn as below in Fig-20.

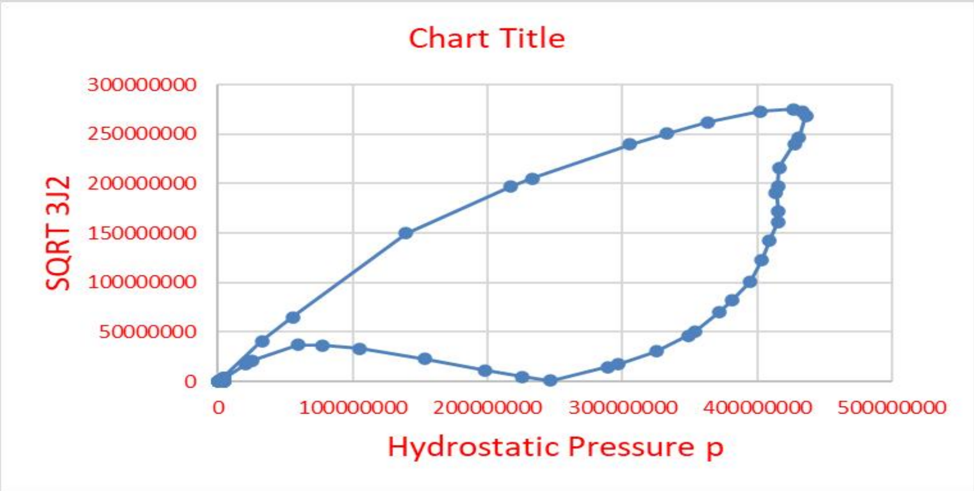


Fig-20

4.0 CONCLUSION:

The Impact of a rigid explosive missile on a Concrete Barrier was programmed to be done numerically by the author as he can make variations in the mathematical model and observe the trend of the result.Initially the author was not sure about the contribution of reinforcement in the analysis. So every effort was taken to map the stress time history in steel rebar component and map the stress(Von.Mises) out put along height of the wall from base 0m including Stress output in the impact zone .The twain effect of Blast and Impact has off course damaged the Concrete wall of thickness 10 and 15 cm but Steel rebar couldn't be yielded in any of the model cases.Even one additional model RCCBox-2F was also analysed with reduced diameter of rebar steel with yield strength 250E+06Pa (from 36mm to 20mm) also couldn't reach 80% of the yield value.

The other findings of this paper is all formats of stresses e.g; Von Mises,Principal,Normal ,Shear etc were obtained from the analysis for Concrete and Steel members due to Blast wave pressure and combined effect of blast and impact separately from a distance of 3.7m and height 10m from ground though reflection from ground could not be picked up as ground earth was not modeled in the analysis due to restriction in the memory.

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