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Analysis Of RC Structures Subject To Vibration By Using Ansys

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ABSTRACT

Recent historic events have shown that buildings that are designed in compliance with conventional building codes are not necessarily able to resist blast effects. It was observed in the past events that progressive or disproportionate collapse generally occurred due to deficient blast performance of the structure, albeit in compliance with conventional design codes. In the past, safety of structures against blast effects was ensured, to a limited extent, through perimeter control; which minimizes damage by preventing the direct impact of the blast effects on the building. With the emergence of blast resistant structural design, methodologies to inhibit progressive collapse through the structural components performance can be developed, although there are no available adequate tools to simulate or predict progressive collapse behavior of concrete buildings with acceptable precision and reliability. This paper presents part of an effort to find an affordable solution to the problem. State of the art review of the blast analysis and progressive collapse analysis procedures will be presented. Preliminary analysis has been carried out to establish the vulnerability of a typical multistory reinforced concrete framed building in Riyadh when subjected to accidental or terrorist attack blast scenarios. In addition, the results of the blast vulnerability assessment will be used to develop mitigation approach to control or prevent progressive collapse of the building. For protective structures, reinforced concrete is commonly used. Concrete structures subjected to explosive loading in a combination of blast and fragments will have very different response than statically loaded structure. During the blast and the fragment impacts the structure will shake and vibrate, severe crushing of concrete occurs and a crater forms (spalling) in the front of the concrete; for large penetration, scabbing may occur at the backside of the wall, or even perforation, with a risk of injury for people inside the structure. This thesis is intended to increase the knowledge of reinforced concrete structures subjected to explosive loading, i.e. effects of blast and fragmentation. A further aim is to describe and use the non-linear finite element (FE) method for concrete penetration analyses. Particular attention is given to dynamic loading, where the concrete behavior differs compared to static loading. The compressive and tensile strengths increase due to the strain rate effects. Initial stiffness increases, and moreover the concrete strain capacity is increased in dynamic loading. Traditionally, for prediction of the depth of penetration and crater formation from fragments and projectiles, empirical relationships are used, which are discussed here together with the effects of the blast wave that is caused by the explosion. To learn more about the structural behavior of concrete subjected to severe loading, a powerful tool is to combine advanced non-linear FE analyses and experiments. A trustworthy model must be able to capture correct results from several experiments, including both the depth of penetration and the crater size. In this thesis, FE analyses of concrete penetration with steel projectiles have been performed and compared to existing experimental results.

KEYWORDS: Analysis, RC Structures, Vibration, Using Ansys

I INTRODUCTION

Concrete structures are usually large and massive. For protective structures, e.g. civil defense shelters, concrete is commonly used. For civil defense shelters the main threat arises from explosions caused by military weapons, such as conventional and nuclear weapons; the latter are not considered in this thesis. Chalmers University of Technology has long collaborated with the Swedish Rescue Services Agency. In earlier projects a combination of experiments and non-linear finite element (FE) analyses of a new reinforcement detailing in frame corners of civil defense shelters has been carried out at Chalmers; see Plos (1994), Johansson (1996), Johansson and

Karlsson (1997), and Johansson (2000). These works have resulted in a new reinforcement detailing that has been introduced in the Swedish Shelter Regulations, Swedish Rescue Services Agency (1998). The experiments and appertaining FE analyses mentioned above have been performed for static loading. However, a civil defense shelter must resist transient loading caused by explosions and falling debris from a collapsing building. Non-linear FE analyses have been performed by Johansson (1999) and Johansson (2000), where the blast wave from the detonation was taken into account, and a study of falling debris from a collapsing building was carried out. In this work it was shown how the shelter subjected to blast wave was responding at the most critical stage for the first few milliseconds. If the load was applied fast enough, some parts of the structure were not aware of the loading where other parts of it had already gone to failure. Furthermore, it was shown that the civil defense shelter could withstand the design load for the blast. In addition, from a detonation of a General Purpose (GP) bomb, besides the shock wave, fragments will fly against the civil defense shelter. The influence of the fragments that impact the shelter has not been taken into account by the earlier projects at Chalmers, Concrete Structures. The work presented in this thesis is a part of a research project where the long-term aim is to increase the knowledge of reinforced concrete structures subjected to explosive loading, i.e. combination of blast wave and fragmentation. To reach the aim, a powerful tool is to combine experiments with advanced non-linear FE analyses. The work presented in this thesis is intended to give a strong basis of knowledge in the field of structures subjected to explosive loading. This includes the weapon effects, i.e. blast and fragmentation, knowledge of the material behavior for concrete subjected to severe dynamic loading, and the damage mechanisms. Analyzing a civil defense shelter subjected to explosive loading is very complex, since both the shock wave and fragmentation from a detonation must be included in the analyses. In this work the analyses are limited to a steel projectile impacting a concrete target. The research area in this thesis is to study reinforced concrete structures subjected to an explosive loading from conventional weapons. From a high-explosive bomb, the explosive weight causes a blast wave and fragments fly in all directions from the bomb case. The physics of the detonation process is of interest, from initiation to the formation of the shock front, blast wave and fragmentation. Depending on the distance between the charge and target, the fragments can impact the target before, at the same time or after the blast wave.

A concrete structure subjected to impulse loading will have a very different response than a statically loaded structure. When fragments fly into a concrete target, spalling occurs in the front of the concrete surface as a result of the direct impact. When a shock wave propagates through the concrete and reaches the backside of the construction, it will reflect as a tensile wave, since concrete is very weak in tension, and this will lead to scabbing at the backside. Design against fragments and projectiles is critical and an important issue for protective structures. To predict the depth of penetration in concrete targets, empirical equations have been developed from large series of experiments. The depth of penetration is a function of the impact velocity, mass, and form of the fragment or projectile, and of the target material. For concrete, the latter parameter is normally related to the compressive strength. Furthermore, using non-linear FE analyses of concrete penetration is an issue, where the depth of penetration and crater size is of interest. In this thesis, the FE programs Ansys/Explicit and AUTODYN have been used.

II. BLAST, STRESS AND SHOCK WAVE THEORY

To understand the behavior of concrete structures subjected to severe loading from military weapons, the nature and physics of explosions and the creation of a blast wave and reflections from a bomb must be understood. When the blast wave hits a concrete surface, a shock wave propagates through the concrete. There are two main theories to describe the response, the Eulerian and Lagrangian methods, which are further described. When treating the shock wave with the Eulerian method, where a fixed reference in space is chosen and the motions are derived with respect to that region, the shock wave theory is based on the conservation of mass, momentum and energy. When treating the shock wave by the Lagrangian method, with moving reference, the stress wave theory is based on the classic wave equation of motion, where equilibrium and compatibility are considered. An explosion is characterized by a physical or a chemical change in the material, which happens under sudden change of stored potential energy into mechanical work, with creation of a blast wave and a powerful sound; see FortH1 (1987). The explosive material can react in two ways, as a deflagration or a detonation. For deflagration, the chemical change in the reaction zone occurs below the sonic speed through the explosive material. In the case of a detonation, the chemical change in the reaction zone occurs over the sonic speed through the explosive material. In military situations, detonations are most common; for example, if a TNT charge explodes, this means that it decays as a detonation. In present thesis, by explosion is meant a detonation unless stated otherwise.

2.1 BLAST WAVES AND REFLECTIONS

A shock wave resulting from an explosive detonation in free air is termed an air-blast shock wave, or simply a blast wave. The blast environment will differ depending on where the explosion takes place. In the case of an airburst, when the blast wave hits the ground surface, it will be reflected. The reflected wave will coalesce the incident wave and a much front is created. The pressure–time history of a blast wave can be illustrated with a general shape. The illustration is an idealization for an explosion in free air. The pressure–time history is divided into a positive and a negative phase. In the area under the positive phase of the pressure–time curve. For the negative phase, the maximum negative pressure, P^-, has much lower amplitude than the maximum overpressure. The duration of the negative phase, T^-, is much longer compared to the positive duration. The negative impulse, i^-, is the area under the negative phase of the pressure–time curve. The positive phase is more interesting in studies of blast wave effects on concrete buildings because of its high amplitude of the overpressure and the concentrated impulse where p(t) is the overpressure at time t, and T^+ (the positive duration) is the time for the pressure to return to atmospheric pressure, p_0,. By selecting a value for the constant b, various pressure–time histories can be described. The peak pressure, P_S, is dependent on the distance from the charge and the weight of the explosives. In addition, if the peak pressure, the positive impulse and the positive time duration are known, the constant *b* can be calculated, and then the pressure–time history is known. Conventional high explosives tend to produce different magnitudes of peak pressure. As a result, the environments produced by these chemicals will be different from each other. The peak pressure, the positive duration time and the positive impulse are now functions of *Z*, and the pressure–time history can be described.

2.2BLAST WAVE REFLECTIONS

When a blast wave strikes a surface, which is not parallel to its direction of propagation, a reflection of the blast wave takes place. The reflection can be either normal reflection or an oblique reflection. There are two types of oblique reflection, either regular or Mach reflection; the type of reflection depends on the incident angle and shock strength.

2.2.1 NORMAL REFLECTION

The medium has a particle velocity, U_X, before the incident shock wave, U_S, passes the medium; after passage the particle velocity increases to U_P. Furthermore, the overpressure increases from p_X to p_Y (p_X refers usually to atmospheric overpressure), the temperature increases from T_X to T_Y and the sonic speed increases from a_X to a_Y (a_X is approximately 340 m/s in undisturbed air).

III MACH STEMS FORMATION

There is a critical angle that depends on the shock strength, where an oblique reflection cannot occur. According to Baker (1973), Ernst Mach [Mach and Sommer (1877)] showed that the incident shock and the reflected shock coalesce to form a third shock front. The created shock front is termed the Mach stem or Mach front, which is moving approximately parallel to the ground surface, with increasing height of the shock front. The point where the three shock fronts meets is termed the triple point. The Mach front and the path of the triple point.

3.1 STRESS WAVES, REFLECTIONS AND TRANSMISSION

When a concrete member is subjected to dynamic loading, a stress wave will propagate through it. The stress wave propagates in the longitudinal and the transverse directions in the structure. By using constitutive laws, equilibrium and compatibility the classic wave equation in one dimension for elastic materials can be derived; In real structures when the blast wave or fragment hits the concrete, the concrete behavior is far from elastic, and the elastic wave equations is not valid. However, the elastic assumption of the classic wave equation illustrates phenomena for concrete in dynamic loading.

The particle velocity is proportional to the stress and indirectly proportional to the acoustic impedance (ρ*c*). The acoustic impedance is the resistance to the wave propagation, where the mass and stiffness are parameters that determine the particle velocity in the medium. By using this model, comparison of concrete and steel shows that the particle velocity is approximately four to five times higher for concrete than for steel.

3.1.1 SHOCK WAVES

By choosing a fixed reference in space (the shock front), where the material motions are derived with respect to that region, the fundamental shock wave equations, known as the Rankine-Hugoniot equations, are derived from the equations for conservation of mass, momentum, and energy in the medium. Consider the one-dimensional model , where the material is moving with a velocity of U_0 against the shock front, and the material velocity is U_1 after passing the shock front. The pressure is P_0 and the density ρ_0 before the material reaches the shock front, and the pressure is P_1 and density ρ_1 after passage.

IV CONCRETE UNDER SEVERE LOADING

To understand the behavior of concrete structures subjected to severe loading from military weapons, the nature and physics of explosions, the creation of a blast wave and reflections must be known, as described in Chapter 2. Furthermore, fragments will be released from the bomb case, which will fly against the structure. The fragment size, area density (kg/m^2) and striking (impact) velocity are important parameters for the fracture mechanism in concrete. Prediction of the depth of penetration is an important factor for design of protective structures. These subjects will be discussed in this chapter. The effects in concrete slabs loaded by fragments and combined loading of blast and fragment into concrete walls are discussed as well.

4.1 WEAPON SYSTEMS

Weapon systems can be divided into conventional weapons, nuclear weapons, biological and chemical weapons. Nuclear weapons, the most powerful weapon systems in human history, are of two kinds, A-bomb (atomic) and H-bomb (hydrogen). An A-bomb is created by fission of uranium and an H-bomb by fusion of hydrogen. The H -bomb gives much higher energy release than the A-bomb. Biological weapons cause diseases by releasing bacteria or viruses; an example is anthrax. Chemical weapons are direct chemical attacks. An example is mustard gas, first introduced in World War I.

However, the aim in this thesis is to study the effects of conventional weapon attacks in reinforced concrete structures, especially the combination of blast wave and fragments. Conventional weapons are divided into direct and indirect projectiles with and without explosives; see FortH1 (1987). The damage of a direct projectile without explosives is caused by the mass and velocity of the projectile. For direct projectiles with explosives such as grenades, bombs, torpedoes, missiles and robots, the damage is caused not only by the primary kinetic energy from the projectile, but also by the shock wave due to the explosion.

Furthermore, fragments are produced from the projectile case, which will fly against the target. Indirect projectiles are weapons that produce a projectile after being discharged.

4.1.1 FRAGMENTATION:

When high explosives such as grenades, bombs, torpedoes, missiles or robots detonate, fragments will fly out in all directions when the case is broken. The fragments from the same kind of weapon can be of different sizes. An example of fragmentation of a 15.5 cm bursting shell is shown in Figure 4.1.

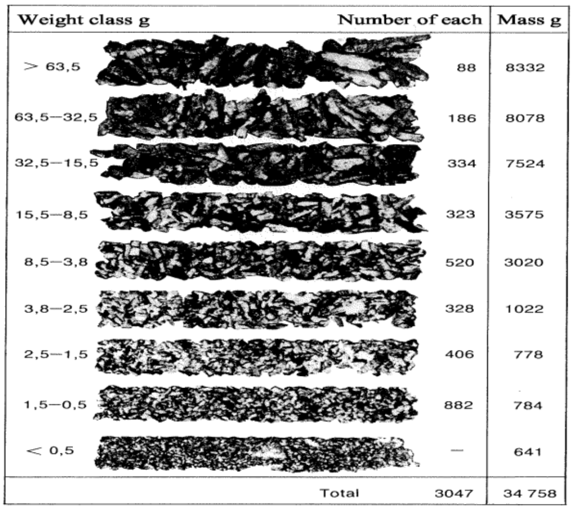

Figure 4.1 Fragmentations Of 15.5 Cm Bursting Shell, Based On Forth1 (1987).

The damage to concrete depends on the fragment properties, i.e. the striking velocity, mass and area density. In the literature there are empirical formulas – as Janzon (1978), ConWep (1992), Krauthammer (2000), or FortH1 (1987) – for estimating the velocity of the fragments. Here formulas from FortH1 (1987) are presented.

The initial velocity of the fragments depends on the amount of the explosive material and the size of the case, which can be estimated with equation (3.1), where Q is the charge weight and M_h is the weight of the case.

$$v_i = 2400(1-e^{-2Q/M_h}[m/s] \qquad (3.1)$$

Where r is the distance, v_i is the initial fragment velocity from equation (3.1) and m_f is the fragment mass. Fragments from an explosion can fly through the air over very long distances, more than 1000 m for heavy fragments; FortH1 (1987).

According to Swedish Rescue Services Agency (1994), a shelter must be able to resist the effect of a 250 kg GP bomb (with 50 weight per cent TNT) that bursts freely outside from a distance of 5 m from the shelter. The fragments masses from a 250 kg GP bomb are normally distributed from 1 to 50 g; FortH1 (1987). By using equations (3.1) the impact velocity at a distance of 5 m varies between 1650-1950 m/s for fragments with mass of 1 to 50 g. fragments velocities from a 250 kg GP bomb are shown for varying fragment weights.

4.2 PENETRATION WITH STEEL FRAGMENTS INTO DIFFERENT MATERIALS:

The depth of penetration depends on the fragment mass, form, velocity and inclination angle of impact, and the material of the target. For spherical fragments, it has been empirically found by Janzon (1978) that the velocity for perforation at different thicknesses of steel plates is where θ is a constant depending on the form of the fragment and the target material. The inclination of the impact is α, the mass of the fragments is m_f, and the thickness of the steel plate is t. An example of penetration with fragments of 15.5 cm bursting shell into soft steel is shown in Figure, with an impact inclination of 90°.Approximate depth of penetration into other materials than steel is given by multiples of the depth of penetration for soft steel by a factor. By using a direct formula, in Krauthammer (2000), the depth of penetration can be estimated for fragments penetrating massive concrete. For equations, see the Appendix D. The depth of penetration is a function of the fragment weight, the striking velocity and the concrete compressive strength. The penetration depth for fragments into massive concrete is shown. However, for a concrete structures, for 70 % penetration, perforation may be expected; see Krauthammer (2000). According to Swedish Rescue Services Agency (1994), shelter above ground must have a minimum thickness of 350 mm. For the normally distributed (1–50 g) fragments from a 250 kg GP bomb with 125 kg TNT, perforation will not be a problem. However, if single fragments of large size are released from the bomb, perforation may become a problem. The required thickness of a concrete wall to just prevent perforation for fragment weights from 5 to 400 g with striking velocities up to 3000 m/s. As seen, both the striking velocity and the mass are important factors for the design of protective structures. The area marked grey gives a thickness above 350 mm massive concrete (the required minimum thickness of a civil defense shelter above ground).

4.2.1 SPALLING AND SCABBING

Concrete has a high compressive strength but is very weak in tension. The fragment or projectile impact will cause severe cracking and crushing in the concrete, which must be supported by reinforcement in order to prevent failure. When a fragment or a projectile hits a target of concrete, it will penetrate into the concrete and the impact will cause crushing of the material at the point of contact (spalling) and possible scabbing on the backside of the wall; When 50 % penetration is achieved, scabbing will become a problem.

4.3 CONCRETE PENETRATION WITH STEEL PROJECTILE:

Reinforced concrete structures for military protection have been the most widely used material. Protective structures in concrete have been built since the beginning of the $20^{\text{th century}}$. During and after World War II there were large research projects for studying penetration effects on concrete. Poncelet (1829), according to Bulson (1997) is known as the first who came up with a penetration formula for projectiles. He assumed that the course of forces between the projectile and the target was a function of the projectile weight, diameter, nose shape, impact velocity, v_i, and two parameters that took account of the target material. where x is the depth of penetration, and C is a constant which depends on the projectile mass, the nose shape of the projectile, the diameter of the projectile and a parameter that takes account of the target material. For concrete this last parameter is normally related to the compressive strength.

Hughes (1984) derived an empirical formula;. He used the same principal ideas that Bergman and Beth used, i.e. that the depth of penetration was dependent on the projectile mass, the nose shape of the projectile, the diameter of the projectile and a parameter that takes account of the target material. However, Hughes used the tensile strength of the concrete as a parameter, whereas Bergman and Beth had used the concrete compressive strength. Furthermore, the concrete strength depends on the strain rate. This approach gives more realistic behavior of the concrete.

V FE ANALYSES OF CONCRETE

PENETRATION

A FE model with good material models should be able to predict the crater size and the depth of penetration of a steel projectile impacting a concrete target. In this chapter, FE analyses have been compared to experimental results. To ensure that the model can predict the depth of penetration and crater size, results from more than one experiment must be reproduced. In this thesis two experimental series with a total of 6 shots have been compared. In a study by Leppänen (2001), FE program ANSYS/Explicit was evaluated, which is summarized. Furthermore, analyses with AUTODYN by using the RHT model for the concrete target have been carried out, as described. Two experimental series have been compared with FE analyses: first, with a 6.28 kg projectile impacting a concrete cylinder, by Hansson (1998), and secondly with a 0.906 kg projectile impacting a concrete cylinder, by Forrestal et al. (1994). The first series both the Lagrangian and Eulerian methods, and the second series the Lagrangian method have been used for the non-linear FE analyses. In the first of these series, the 6.28 kg steel projectile impacted a concrete cylinder with a striking velocity of 485 m/s. Two shots are compared, one with support and the other without any support at the backside of the target. In the second series, with a projectile mass of 0.906 kg, the results of several striking velocities from 277 m/s to 800 m/s are compared with FE analyses. In the experimental series reported by Hansson (1998), a 6.28 kg steel projectile was used with a length of 225 mm, diameter of 75 mm, density of 7830 kg/m^3, bulk modulus of 159 GPa, shear modulus of 81.8 GPa, and yield stress of 792 MPa. The target was a concrete cylinder cast in a steel culvert with a diameter of 1.6 m and a length of 2 m. The concrete cube strength was approximately 40 MPa (tested on a 150 mm cube). Two shots were made with the same impact velocity, first with support and secondly without support at the backside of the target.

5.1 LIGHT STEEL PROJECTILE

In the series reported by Forrestal et al. (1994), projectiles made from 4,340 steel rods and heat-treated to a hardness of Rc 43-45 were used. Moreover, filler material was used in the projectiles, with a density of 1580 kg/m3. The projectile length, l, was 242.4 mm; its diameter d was 26.9 mm, and the ogival radius s was 53.8 mm.

The concrete targets were cast in galvanized, corrugated steel culverts with diameter of 1.37 m and target length of 0.76 m. The shots had striking velocities of 277 m/s and 499 m/s. For two other experiments with impact velocities of 642 and 800 m/s, the target diameter was 1.22 m and the length 1.83 m. The concrete had a density of 2370 kg/m^3 and the unconfined uniaxial compressive cylinder strength varied between 32.4 and 35.2 MPa. Totally four experiments are compared in this thesis, and their results are summarized.

5.2 ANALYSES WITH AUTODYN:

The EOS used in the numerical model is a combined P-Alpha EOS and polynomial EOS; The material parameters is shown in Appendix A. Detailing of the material parameters are described in AUTODYN (2001); here the compaction phase (polynomial EOS) is chosen to have the default values from the material library in AUTODYN. In the experimental series with 6.28 kg projectile, the density of the concrete is assumed to be 2400 kg/m^3; see Betonghandboken (1994) (density of plain concrete).

The constitutive model used in the study is the RHT model, as described. Parameters A and N describe the failure surface (compressive meridian); see Appendix A for values. From the knowledge of the concrete behaviour in tri–axial stress states, the parameters can be decided. In this thesis, parameters used are calculated according to the model proposed by Attard and Setunge (1996 for low confining pressures. The proposed model by Attard and Setunge (1996) is limited to low confining pressures. The material parameters for the constitutive model used in analyses are shown in Appendix A. In the experimental series by Hansson (1998), the tested concrete cube strength was 40 MPa. However, the cylinder strength is used as input in the material model, which is calculated from the cube strength according to the CEB-FIB Model Code 1990 (1993). In addition, the CEB Model Code 90 is used for calculating the material parameters, for instance the bulk modulus or tensile strength. The same model that was used previously for comparison with experimental results from the larger projectile having a mass of 6.28 kg – can predict the depth of penetration of the smaller projectile having a weight of approximately 0.906 kg. In Figure 6.8 the crater size and depth of penetration are shown from the analyses. The depth of penetration, maximum crater diameter and the lateral damage are increased for higher impact velocities. In these analyses the yield strength of the steel in the projectile was 1448 MPa. The crater size is smaller for the light projectile than in experiments with the heavier projectile (with mass of 6.28 kg and diameter of 75 mm). For the higher impact velocities, the steel strength of the projectile is important. The projectile deforms when using the true yield strength of the material in the material model (von Mises). However, when using the ultimate strength of the steel the projectile will not deform. Ansys/Explicit has no material model that can combine non-linearity of compression and tension at the same time for one element. Normally, two different material models are combined: for areas where the compressive stresses are high, the compression model is used, and for areas where tensile stresses are high (where the compressive stresses are linear) the tension model is used. With a combination of a compression model and a tension model, it is possible to achieve results that agree with experiments regarding the depth of perforation and the crater size. However, Ansys/Explicit cannot be used for general impact loading, since by using the method with combined models there can be errors in the analysis even if the end result seems to be correct. First of all, the stresses will vary from high compressive stresses to high tensile stresses; this leads to defaults in the analysis. Secondly, the distinction in where to use the compression and tension models is hard to draw, especially for analysis with multiple hits, such as fragments impacting a concrete wall. AUTODYN, on the other hand, was created for analyses with large deformations. For reliable model, results from several experiments must be reproduced, regarding both the crater size and the depth of penetration. For example, correct results on depth of penetration can be obtained by changing, for instance, the residual strength or the erosion criterion (with the Lagrangian method).

In this thesis, numerical comparisons to experiments by Hansson (1998) were made with both Lagrangian and Eulerian methods. The erosion criterion, the instantaneous geometric strain for Lagrangian analyses, was calibrated to fit the experimental results. This erosion criterion was further used for comparison with another experimental series, in Forrestal et al. (1994), with varying impact velocities for the projectile. For the experiments by Forrestal et al. (1994) the projectile was modeled with the von Mises material model. The model has no hardening, and the difference between the ultimate strength and the yield strength of the steel is so great that, by using the yield strength of the material, the depth of penetration will be underestimated. Therefore, analyses using the ultimate strength as the yield strength in the model were also carried out. This gives lower and upper limits according to the strength of the steel in the projectile. At low impact velocities the difference in depth of penetration is negligible, but for the higher impact velocities the increase of the steel strength is important in the analysis the projectile will deform when the increase in steel strength is not modelled. Hence, modeling the steel accurately, i.e. including hardening in the material model, is important at higher impact velocities.

VI. THE FINITE ELEMENT ANALYSIS

6.1 GENERAL

The Finite Element Analysis (FEA) is a numerical method for solving problems of engineering and mathematical physics. Useful for problems with complicated geometries, loadings, and material properties where analytical solutions cannot be obtained. Finite element analysis (FEA) has become commonplace in recent years, and is now the basis of a multibillion dollar per year industry. Numerical solutions to even very complicated stress problems can now be obtained routinely using FEA, and the method is so important that even introductory treatments of Mechanics of Materials such as these modules should outline its principal features. In spite of the great power of FEA, the disadvantages of computer solutions must be kept in mind when using this and similar methods: they do not necessarily reveal how the stresses are influenced by important problem variables such as materials properties and geometrical features, and errors in input data can produce wildly incorrect results that may be overlooked by the analyst. Perhaps the most important function of theoretical modeling is that of sharpening the designer's intuition; users of finite element codes should plan their strategy toward this end, supplementing the computer simulation with as much closed-form and experimental analysis as possible. Finite element codes are less complicated than many of the word processing and spreadsheet packages found on modern microcomputers. Nevertheless, they are complex enough that most users do to program their own code. A number of prewritten commercial codes are available, representing a broad price range and compatible with machines from microcomputers to supercomputers1. However, users with specialized needs should not necessarily shy away from code development, and may the code sources available in such texts as that by Zienkiewicz2 to be a useful starting point. Most finite element software is written in Fortran, but some newer codes such as felt are in C or other more modern programming languages.

VII ANSYS RESULT

Deflection along x-positive direction:

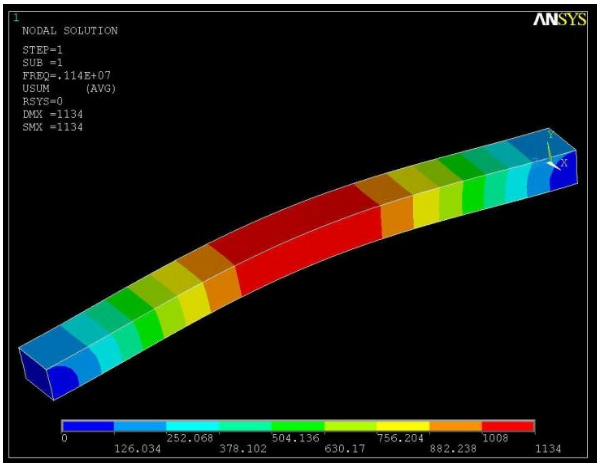

Figure. 7.1 Deflection along x-positive direction

Graph result in x positive -direction:

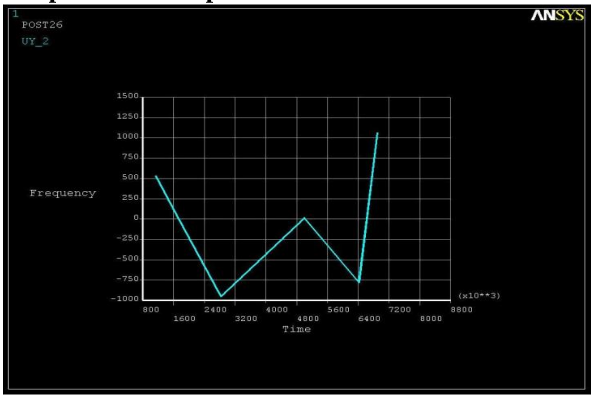

Figure..7.2: Graph result in x positive -direction

Deflection along y positive -direction:

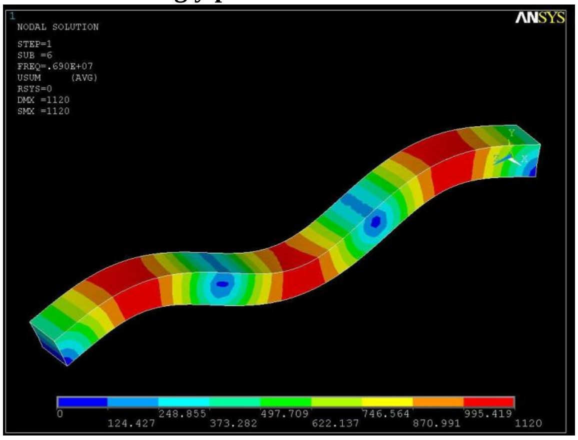

Figure.. 7.3 Deflection along y positive -direction

Graph result in y positive -direction:

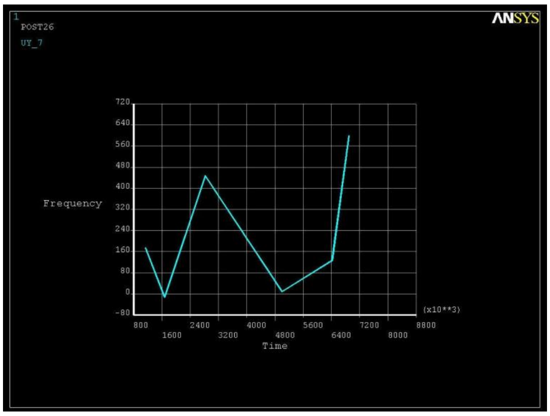

Figure.. 7.4 Graph result in y positive –direction

Deflection along z- positive direction:

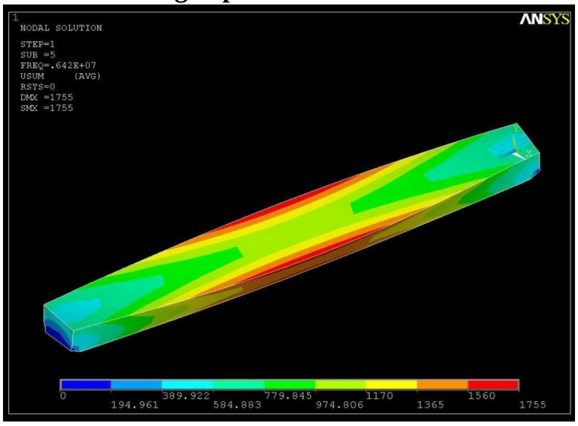

Figure.. 7.5 Deflection along z- positive direction

Graph result in z – positive direction:

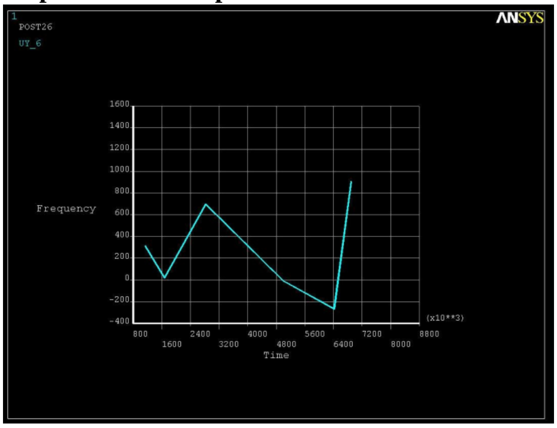

Figure.. 7.6 Graph result in z – positive direction

Deflection along x-negative direction:

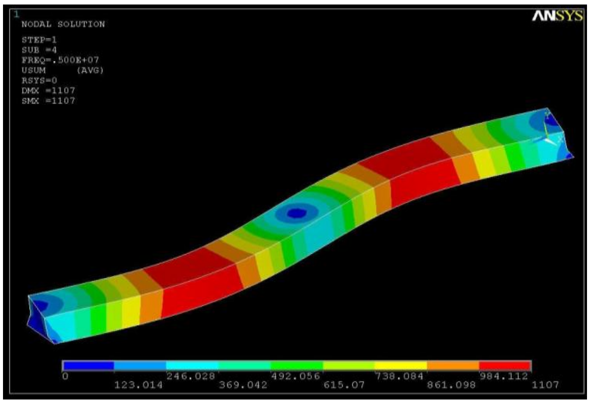

Figure.7.7 Deflection along x-negative direction

Graph result in x –negative direction:

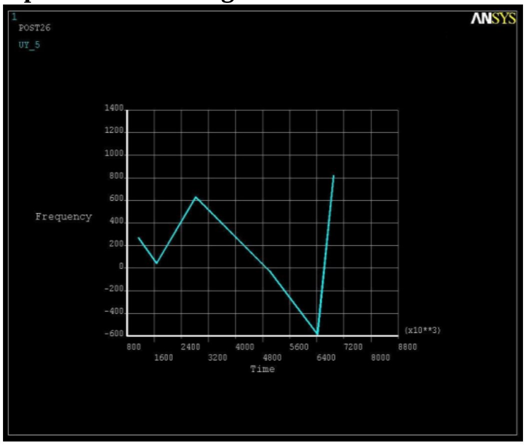

Figure.7.8 Graph result in x –negative direction

Deflection along y-negative direction:

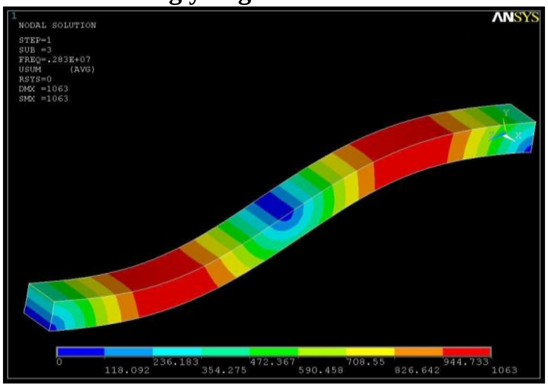

Figure.7.9 Deflection along y-negative direction

Graph result in y –negative direction:

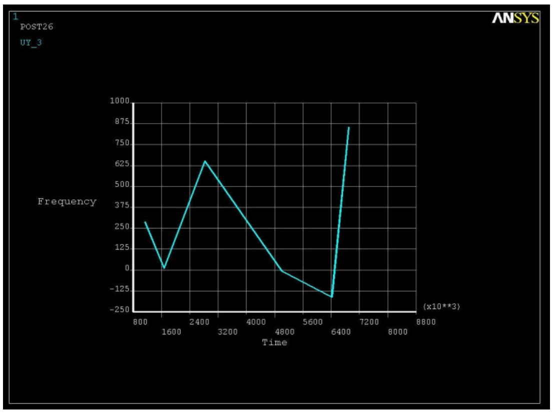

Figure.7.10 Graph result in y –negative direction

Deflection along z-negative direction:

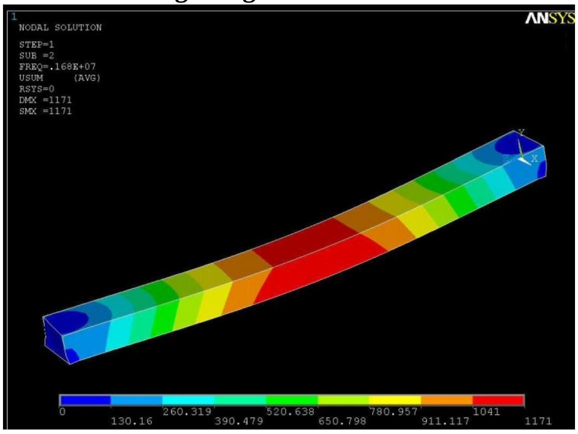

Figure.7.11 Deflection along z-negative direction

Graph result in z –negative direction:

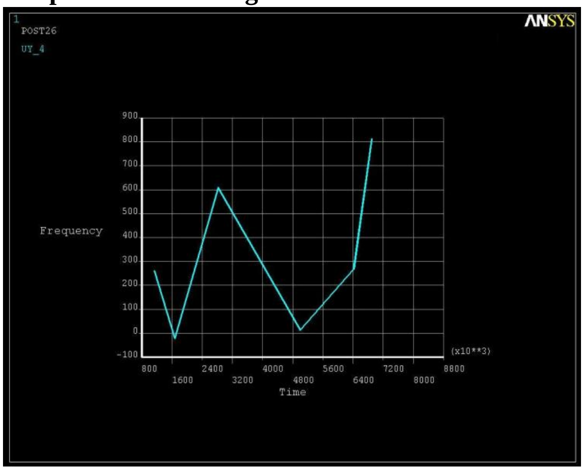

Figure.7.12 Graph result in z –negative direction

VIII CONCLUSION

The main aim of this thesis was to increase the knowledge of concrete structures subjected to explosive loading. A further intention has been to describe how to use the non-linear FE method for severe loading cases. FE analyses with a combination of blast and fragment impacts are very complex; in this thesis the analyses are limited to projectiles impacting a concrete target. The theory of blast waves and their reflections describes the nature of the explosion. By using this, the load can be applied to a concrete structure in a realistic way. The classic stress wave theory describes the stress wave propagation in concrete at dynamic loading for elastic materials. Concrete under severe loading is far from elastic and the classic elastic assumptions are not valid; the shock wave theory is used to describe the material behaviour. The fundamental shock wave equations are based on the equations for conservation of mass, momentum and energy. The concrete behaviour changes under dynamic loading. The initial stiffness, the ultimate strength, in both compression and tension will increase, and the concrete strain capacity is extended in dynamic loading. Furthermore, the fracture of a concrete member changes at dynamic loading and multiple fracture planes are obtained. For design of protective structures, their penetration by fragments and projectiles is an important issue, and traditionally empirical equations are used to predict the depth of penetration. In the literature there are empirical equations to predict the depth of penetration for fragments and projectiles impacting a concrete target. The empirical equations give a good prediction of the depth of penetration, but will not describe the structural behavior of the concrete structure. To increase the knowledge of concrete subjected to severe loading, a combination of experiments with the FE method is a powerful tool. It can be used for detailed behavior. A reliable model must be able to describe experimental results. The RHT model in AUTODYN seems to be able to predict both the depth of penetration and the crater size for projectile impact analyses in concrete.The material parameters that mostly influence the depth of penetration are the concrete compressive strength, the strain rate dependency for compression, and the level of the residual strength. Furthermore, the numerical mesh influences the depth of penetration. The mesh dependency is commonly treated by refining the mesh until the differences are negligible. However, the results obtained in this thesis are reasonable. The material parameters that mostly influence the size of the crater are the tensile strength, the fracture energy and the strain rate dependency for tension.

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