BLAST RESPONSE OF TELECOMMUNICATION MASTS: AN ANALYTICAL APPROACH

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Abstract
This paper presents a mathematical model for the study of the blast response of telecommunication towers. Telecommunication towers in the vicinity of explosions are subjected to very large dynamic loads from blast overpressures. These dynamic loads cause both local and global damage. These damage include buckling of members, overturning of mast, shear on bolts and fracture of mast members. Thus, fundamental aim of this paper is to determine the magnitude of loads capable of causing damage on various telecommunication masts.

Using a simplified approach, a rectangular mast is idealised as a continuous beam system with fixed support to the base. Applying assumed mode approach, the equivalent beam system is reduced to a single degree of freedom system (SDOF). Using Duhamel's integral, the structural dynamic problem is solved.

Solutions are obtained for different mast configurations subjected to various levels of blast load. It is observed that the response of the mast is proportional to the natural frequency of the mast. Also, the deflection of mast reduced as the sizes of the members where increased. This implies that deflection was proportional to stiffness of members for masts with similar heights and configurations. Using this approach, a threshold displacement can be set and various blast loads that could cause significant damage to mast can be subsequently obtained.

***Keywords**:* Single Degree of Freedom (SDOF), Elastic-plastic, Resistance Function, Numerical Integration.

Introduction

Terrorist activities in Africa is increasing daily as result of their activities civil infrastructure stand a risk of been damaged. Telecommunication infrastructure suffer significant damage to high blasts. Thus, investigation into the area of dynamic response of structures subjected to high explosive loads is necessary in understanding the effect of these explosions on structures (Hetherington and Smith, 1994; Merx, 1992).

The effect of a bomb is proportional to the stand-off distance of the bomb from the point of detonation. An explosion which occurs close to a building can cause catastrophic damage on the building, which could be less severe if the explosion is further from the target (Baker, 1973; Mendis and Ngo, 2003).

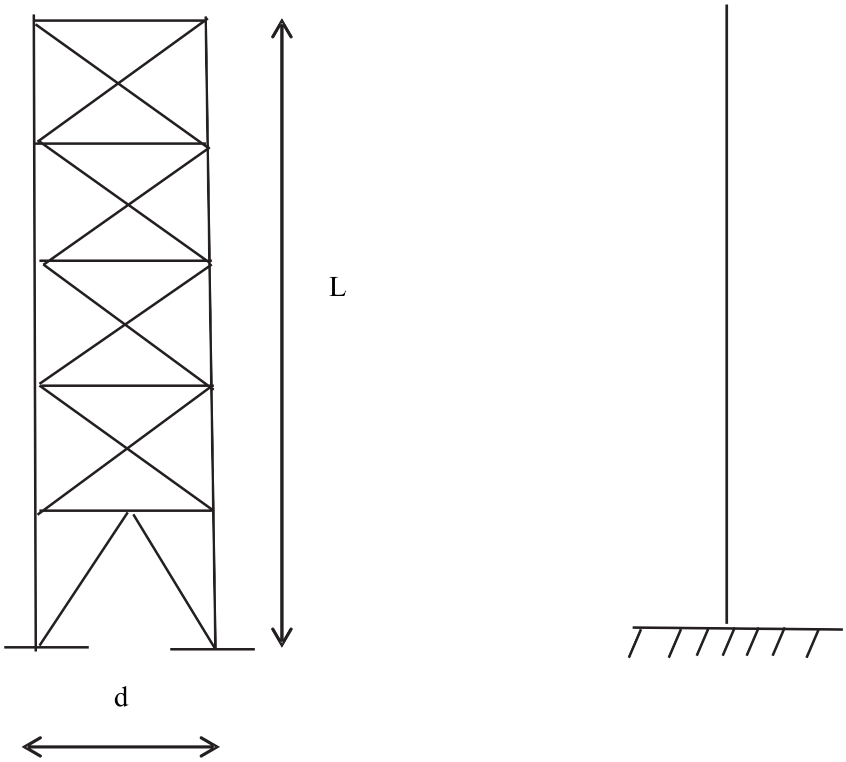
Structures which may be subjected to blast are designed to provide a level of resistance to anticipated blast loads. It is possible to allow for minor damage in blast resistance design, however, such damage must not affect structural integrity. For instance, a threshold level of displacement can be allowed above which the structure can be deemed to have failed (Hinman, 2003).

On the general effect of blast loading on structural elements, various researcher have studied the effect of blast on reinforced concrete panels and other sandwiched structures (Selby and Burgan,1998; Lan et al, 2005, Librescu and Heng, 2004; Khaloo and Tariverdilu 2001). Louca and Boh (2004) worked on design and analysis of blast wall and observed their response to large overpressures. Magnusson and Hallgre (2004) carried out blast analysis of reinforced concrete beams. The behaviour of dynamically loaded structures is different from statically loaded structures. Newmark et al (1982) presented analytical procedures used in determining the solution of different equations associated with dynamic problems.

At this point it should be noted that the analytical models are normally validated by experimental models (Schleyer et al, 2007). However, in instances where experimental model might be impossible to carry out due to security concerns, analytical models are usually validated with numerical models (i.e. Finite Element models). This research intends to develop simplified analytical model by reducing telecommunications towers to single degree of freedom (SDOF) models and thus obtain maximum displacement. Structures normally have numerous degrees of freedoms. Thus, reducing them to SDOF systems allows the application of Eq (6). Using well know engineering approximations, equivalent mass, stiffness and load of the resultant SDOF model is obtained. Due to the difficulty to conducting full scale experimental test in Nigeria, it is recommended that this research should be taken to the experimental level in future. It is recommend that numerical and experimental models be developed for telecommunication towers in order to increase the understanding of their blast response.

Mathematical Modelling

A typical tower is used in this analysis and the first vibration mode is assumed to be the dominant response mode. Figure 1a shows the view of a typical mast analysed in this work.



a b

Figure 1: Modelled telecommunication tower

The mast of height, L, and depth d is assumed in this model, to be continuous beam of length, L with a fixed support at the base, as shown in Figure 1b. The shape function of the equivalent beam system is as expressed in Eq (1),

$$\text{Ø}(x) = \frac{x^2}{L^2} \qquad (1)$$

Equation 1 satisfies the natural and essential boundary conditions for the equivalent beam shown in Figure 1b. We assume a uniformly distributed self-weight along the length of the mast. Thus, we have:

$$k = \int_o^L EI(\text{Ø}'')^2 \, dx = \frac{4EI}{L} \qquad (2)$$

Also,

$$m = \int_o^L pA\text{ø}^2 \, dx = \frac{pAL}{5} \qquad (3)$$

Where k is the equivalent stiffness of the mast and m is the equivalent mass of the idealised mast. The natural frequency of the system, ω is:

$$\omega_n = \sqrt{\frac{k}{m}} = \frac{4.472}{L}\left(\frac{EI}{pA}\right)^2 \qquad pA\text{ø}^2 \text{ dx} = \qquad (4)$$

Also, the equivalent load is:

$$p = \int_O^L p(x, t)\, \text{ø}\ \text{dx} \qquad (5)$$

Thus, the problem can be broken down into a single degree of freedom system:

$$mx + kx = p(t) \qquad (6)$$

Approach

Eq (6) is solved using the Duhamel's integral method. Here, we assume the response of the system to an impulse dI = p (τ) dτ is called du (t) which is given as:

$$du\,(t) = \left(\frac{dI}{m\omega_n}\right) sin\omega_n\,(t - \ \ ) \qquad (7)$$

The total response at time t will be the sum of the response due to all incremental impulses prior to time, *t*. Thus we:

$$\text{u}\,(t) = \frac{1}{m\omega_n}\int_O^L sin\omega_n\,(t - \ \ )\,d \qquad (8)$$

After simplification we obtain:
For $0 < t < t_d$,

$$\text{u}\,(t) = \frac{P_O}{k}\left\{sin\omega_n\, t\left[sin\omega_n\, t - \frac{t}{t_d} sin\omega_n\, t - \frac{1}{\omega_n t_d} cos\omega_n\, t + \frac{1}{\omega_n t_d}\right]\right.$$
$$\left. - cos\omega_n\, t\left[-cos\omega_n\, t + 1 + \frac{t}{t_d} cos\omega_n\, t - \frac{1}{\omega_n t_d} sin\omega_n\, t\right]\right\} \qquad (9)$$

For $t > t_d$,

$$\text{u}\,(t) = \frac{P_O}{k}\left\{sin\omega_n t\left[-\frac{1}{\omega_n t_d} cos\omega_n t + \frac{1}{\omega_n t_d}\right] - cos\omega_n t\left[1 - \frac{1}{\omega_n t_d}\text{ sin}\omega_n\, t\right]\right\} \qquad (10)$$

Where P_0 is the peak blast load.

Blast Loads

A Time varying blast load typical of a detonation (i.e. from terrorists) is applied to the beam model and subsequent maximum deflections obtained. The blast load has duration of 0.007seconds and rises from 0 bar to a peak value of 9 bars in 0.0035seconds. Figure 2 shows the duration of the blast load. Extensive literature on the mathematical idealisation of blast and impact loads can be seen in (Hetherington and Smith,1994).

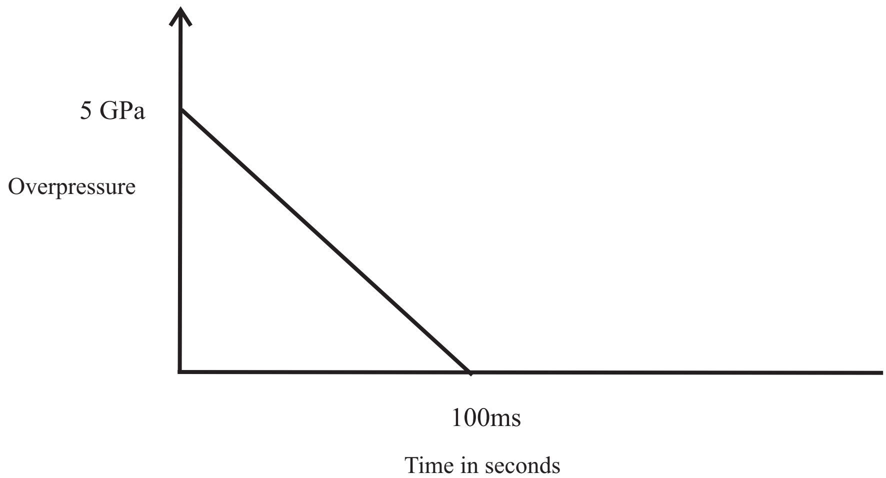


Figure 4. Idealised Time History For Large Explosions

Idealised Beam System Parameters

In this work, we assume a four sided rectangular mast of depth, d and height, L. For each elevation, the corresponding area of top and bottom chord members is represented as A_{ch}. An equivalent second moment of area of the beam can be obtained for a single truss, using the classical equation shown in Eq 11.

$$I = \sum_{I=1}^{2} A_{ch}, i\, d^2 \qquad (11)$$

Where $A_{ch,i}$ is the section area of the chords

d_i is the distance from the centroid of both chords to the centroid of the chord, *I*.

In order to take into account global shear deformations not included in the basic formula presented, a reduced modulus of elasticity is used. Global shear deformation not negligible in trusses, since they result in a variation in length of the diagonal posts. The value of the reduced modulus of elasticity clearly varies depending on the geometry of the truss, the section members, etc. For a truss beam well proportioned

Results and Discussion

An example is presented to illustrate the model presented. Since the aim of this paper is to establish a mathematical model for evaluating the blast response of masts, it is imperative the model is tested with actual mast members. It is not an experimental work, thus, materials are just used to validate the model presented in this paper.

Towers made with 80 x 80 x 8, 120 x 120 x 6 and 150 x 150 x 8 angle were analysed to obtain their response under 10GPa blast load with a duration of 100ms. Tables 1-3 show the maximum displacement obtained for towers made with different members. It is observed that the displacement reduces as the stiffness of the section. It is also observed that the natural frequency and the duration of the pulse is proportional to the maximum displacement obtained. Obtaining the displacement gives an insight into the integrity of the structure. Excessive displacements induces large forces on the hold down bolt on the base of the tower. Depending on the magnitude of the forces, collapse might occur.

Table 1: Maximum displacement for tower made of 80 x 80 x 8 angle

Height, L (m)	80
Member size	80 x 80 x 8 Angle
Breath of tower (m)	2
Blast Load (kN/mm2)	10
Maximum displacement (mm)	**125**

Table 2: Maximum displacement for tower made of 120 x 120 x 6 angle

Height, L (m)	80
Member size	120 x 120 x 6 Angle
Breath of tower (m)	2
Blast Load (kN/mm2)	10
Maximum displacement (mm)	**80**

Table 3: Maximum displacement for tower made of 150 x 150 x 10 angle

Height, L (m)	80
Member size	150 x 150 x 8 Angle
Breath of tower (m)	2
Blast Load (kN/mm2)	10
Maximum displacement (mm)	**50**

Conclusion

The research work was centred on assessing the global damage of telecommunication towers using deflection as the key damage parameter. Excessive deflection results in increased stresses in the hold down bolt at the base of the towers. Thus, ultimately results in collapse. However, local damage might result from explosions.

The procedure developed in this work will aid designers and engineers in preliminary analysis in order to determine the effect of explosions on towers. This consists one of the fundamental aims of this study. Using simplified analytical models can greatly reduce the time devoted for engineering studies and thus reduce the cost of the project.

From the results obtained from the study, the following conclusions can be drawn:

1. The maximum deflection in the tower is a function of the natural frequency of the tower.
2. The maximum deflection in the tower is a function of ration of the duration of the blast to the natural frequency of the tower
3. Large telecommunications towers can be idealised as single degree of freedom system in order to be used for dynamic calculations
4. As the stiffness of the mast increases, its maximum displacement reduces when subjected to blast loads.

References

Baker, W.E. (1973). Explosions in Air. University of Texas Press.

Hetherington, J.G. and Smith, P.D. (1994). Blast and Ballistic Loading of Structures. Butterworth - Heinemann.

Hinman, E. (2003). Retrofitting to resist explosive attack. Presentation to the Existing Building Committee of the SEAONVC

Khaloo,A.R. and Tariverdilu A.S. (2001). Ductility evaluation of confined high strength concrete flexural members. Iranian Journal of Science and Technology, Transaction B,Engineering, Vol.25, No.B1,129-131

Lan, S., Lok, T.S. and Heng, L. (2005). Composite structural panels subjected to explosive loading. Construction and building materials, vol. 19, pp. 387 - 395

Librescu, L. S, and Heng, L. (2004). Linear and non-linear dynamic response of sandwich panels to blast loading. Composites, Part B, vol. 35, pp. 673-683.

Louca, L.A. and J.W.Boh, J.W. (2004). Analysis and design of profiled blast walls, Imperial College London for the Health and Safety Executive.

Luccioni, B. M and Luege, M (2006). Concrete pavement slab underblast loads. International journal of impact engineering, vol. 32, pp 1248-1266.

Magnusson, J. and Hallgre, M (2004). Reinforced high strenght structures and materials. VIS, structures under shocks and impacts VIII, pp 53-62.

Mendis, P and Ngo, T. (2003). Vulnerability assessment of concrete tall buildings subjected to extreme loading conditions. CIB_CTBUH, International Conference on Tall Buildings.

Mendis, A, Ngo T, Gupta and Ramsay, J.(2007). Loading on Structures. EJSE Special Issue.

Merx, W.P.N. (1992). Methods for the determination of possible damage to people and objects resulting from releases of harzadous materials.CPR 16E, TNO, First Edition.

Miyamoto, A. and Nakamura. H (2001). Visualization of impact failure behavior for RC slabs. Proceeding of 3rd International Conference on Concrete Severe Conditions. UBC.

Newmark, N. M. (1995). A method of computation for structural dynamics, ASCE Journal of the Engineering mechanics division, vol. 85, No 8 , pp 67-94.

Newmark, N. M and Hall, W. J.(1982). Earthquake spectra and design. Berkley C. A. Earthquake Engineering Research Institute

Schleyer G.K., Lowak MJ, Polcyn M.A., Langdon G. S. (2007). Experimental investigation of blast wall panels under shock pressure loading. International Journal of Impact Engineering, 34:1095-118.

Selby, C. and Burgan, B. (1998). Blast and fire engineering for topside structures phase 2, Final Summary Report. UK