Ground Shock Resistant of Buried Nuclear Power Plant Facility

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INTRODUCTION

Nuclear Power Plant (NPP) might be subjected to hostile attacks such as Earth Penetrating Weapons (EPW) that carry explosive charges. Explosions of these weapons near buried NPP facility might cause collapse, breaching, spalling, deflection, shear, rigid body motion (depending upon the foundations), and in-structure shock. The occupants and the equipment in the buried facilities are exposed to the in-structure motions, and if they are greater than their fragility values than occupants might be wounded or killed and the equipment might be damaged, unless protective measures will be applied. NPP critical equipment such as pumps are vital for the normal safe operation since it requires constant water circulation between the nuclear reactor and the cooling system, including in case of an immediate shut down. This paper presents analytical- semi empirical formulation and analysis of the explosion of a penetrating weapon with a warhead of 100kgs TNT (Trinitrotoluene*)* that creates ground shock effect on underground NPP structure containing equipment, such as a typical pump. If the in-structure spectral shock is greater than the pump fragility values than protective measures are required, otherwise a real danger to the NPP safety might occur.

NUMERICAL EXAMPLE

Underground explosion creates free field motions formulated by Drake & Little [1], [2], [3]. The analysis of NPP buried facilities resistant to the in-structure shock caused by the external ground motions is based on the response shock spectra method [2],[3],[4]. A response spectrum is calculated and presented on a special figure with four logarithmic axes. Both the spectral motions (displacement, velocity, and acceleration) of a damped structure subjected to support excitations as a function of frequency and the installed equipment fragility spectrum are presented on the same figure (for example see figure 3). If the spectral in-structure motions are greater than the equipment fragility than the equipment is supposed to be damaged with direct implication on the NPP unsafe operation. Hence, for an existing structure the equipment may be mounted to proper isolator. In a new facility external base isolators may decrese the excessive motions, and additional external protective layers may lower the ground shock and the in-structure shock as required. A numerical example of a response spectrum of an underground structure with an internal pump coping with motions caused by explosive charge stand-off distances of 5m and 10m was carried. The configuration of the structure and the explosive charge is presented in Figure 1.

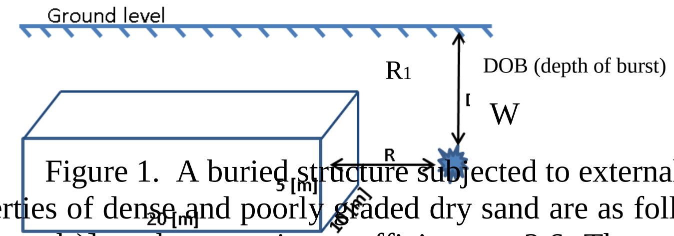

Figure 1. A buried structure subjected to external underground explosion

The soil properties of dense and poorly graded dry sand are as follows [2]: seismic velocity c=365.76 [mps (meters per seconds)], and attenuation coefficient n= 2.6. The explosion parameters are: weight of charge W=100(kgs) $_{TNT}$=73(kgs) C4, and coupling factor f=1 (fully coupled). The US army and air force protective structures manuals [2],[3] suggests the following procedure to evaluate the in-structure response spectrum including some fragility spectrums of typical equipment exposed to shock. The in-structure motions are the average ground motions ranging between the front wall that is exposed directly to the explosion and the back wall. The formulas for the averaged acceleration- A(g's), velocity- V[fps (feet per seconds)], and displacement- D(ft) are:

$$A_{avg} = \frac{50 * f * c * W^{\frac{n+1}{3}} * [R_1^{-n} - R_2^{-n}]}{W^{\frac{1}{3}} * n * [R_2 - R_1]} \quad [g's]$$

$$V_{avg} = \frac{160 * f * W^{\frac{n}{3}} * [R_1^{-n+1} - R_2^{-n+1}]}{(n-1) * [R_2 - R_1]} \quad [fps]$$

$$D_{avg} = \frac{W^{\frac{1}{3}} * 500 * f * W^{\frac{n-1}{3}} * [R_1^{-n+2} - R_2^{-n+2}]}{c(n-2) * [R_2 - R_1]} \quad [ft]$$

f, c, n, W, and R1, R2 are the coupling factor (for deep explosion f=1), soil seismic velocity (fps), dimensionless attenuation coefficient, charge weight (in lbs of C4 high explosive that are equal to 1.37 lbs of TNT), distance between the explosive charge and the front wall, and distance between the explosive charge the back wall.

The values of the free field ground motion are larger than those in the structure since the distances to the various points on the structure's front wall are larger than the shortest distance to the wall center, R_1. Using a reduction factor approach proposed by [2] corrects the ground motions in relation to the explosion stand-off and the structure geometry as shown in Figure 2.

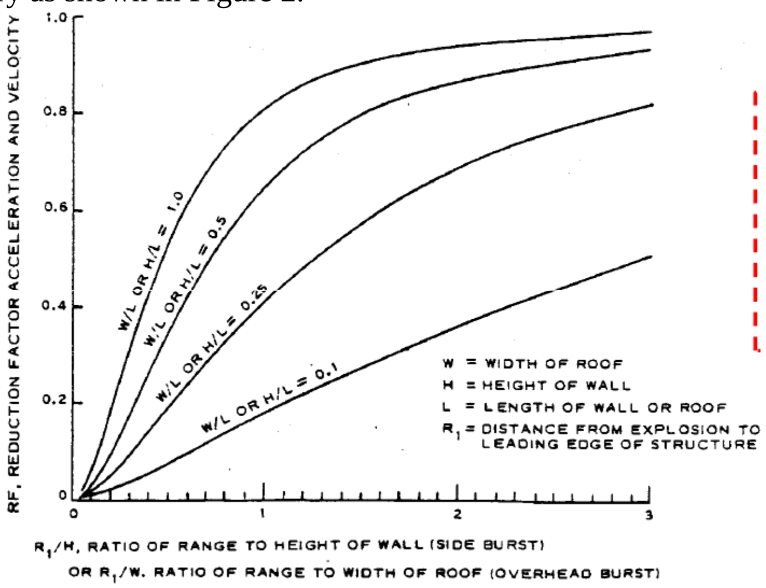

Figure 2. Reduction factor of in-structure acceleration and velocity regarding side burst (H=5m, L=10m)

For small amounts of structural damping (5-10% of the critical damping ratio) it is recommended to multiply the maximum motions by factors 1, 1.5 and 2 for displacement, velocity and acceleration respectively [2]. The physical units of the shock spectrum are taken in inches (in) for the displacement, inches/sec (in/sec) for the velocity and g's (gravity multiplier) for the acceleration. The calculated spectral in-structure motions are shown in Table 1.

Table 1. Spectral motion values due to in-structure shock caused by two external underground explosions

Explosion stand-off, R	Motion type	Average Values	RF-Reduction Factor	Spectrum factor	Spectral motion values
5[m] , 16.4[ft]	Acceleration [g's] Velocity [in/sec] Displacement [in]	9.38 7.52 0.91	0.63	2 1.5 1	18.76[g's] 11.28[in/sec] 0.91[in]
10[m] , 32.8[ft]	Acceleration [g's] Velocity [in/sec] Displacement [in]	1.98 2.96 0.47	0.84	2 1.5 1	3.95[g's] 4.44[in/sec] 0.47[in]

At a stand-off of 5 meters the blast produces base motions that for some frequencies are greater than the pump fragility, hence protective measures are necessary (Figure 3). At a stand-off of 10 meters the blast produces motions that are smaller than the pump fragility and there is no need for protection.

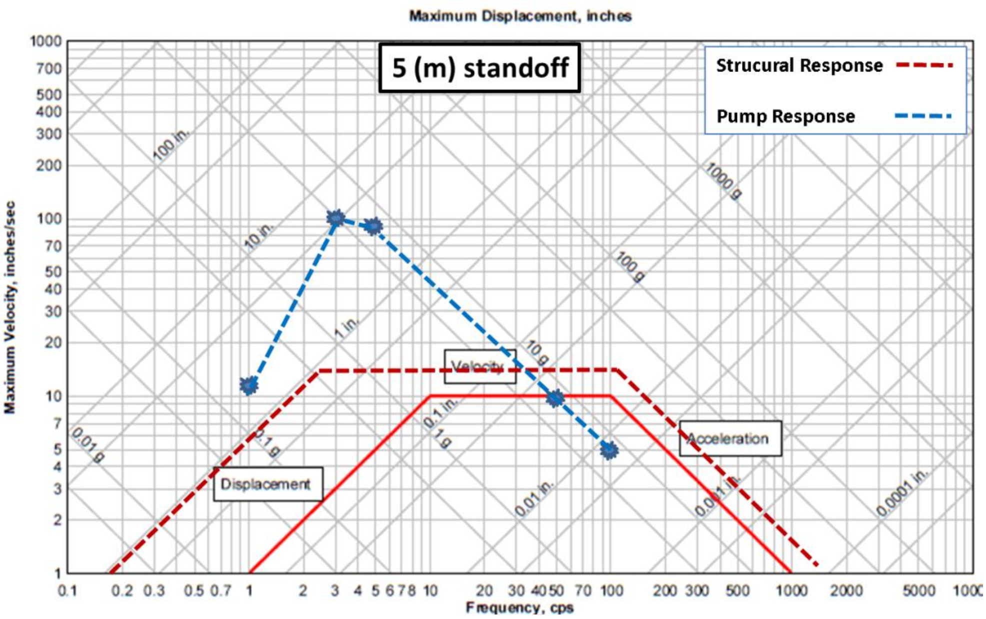

Figure 3. Pump fragility versus in-structure shock spectra due to external 100 kgs. TNT exploding 5 meters from the structure

SUMMARY

Analytical semi empirical method based on Little & Drake method enabled in-structure motion analysis due to external buried explosion. At 5 meters stand-off between the explosive charge and the front wall the blast creates in-structure motions that are greater than the pump fragility. In the case of existing structure protective measures such as mounting the pump to a proper isolator is required. For a new designed structure using base isolators or external protective layers should be considered. Similarly any underground NPP facility may be analyzed.

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