A Novel Structure to Protect Against Explosive Loads

Author:

Jameel Ahmad, The Cooper Union College, 51 Astor Place, New York, NY, 10003, ahmad@cooper.edu

Background Information

Protection of people, buildings, bridges etc. from attacks by car or truck bombs, remote controlled explosives, etc. is of increasing importance and necessity. The explosive forces or blast pressures generated by an explosive device such as a car bomb may be sufficient (depending on the size of the explosive and its distance from the target) to disintegrate, for example, a perimeter concrete wall, thereby causing shrapnel-like pieces of concrete to be launched at high velocity in all directions, and causing additional personal injury and property damage. Conventional reinforced concrete structures typically employ steel reinforcement bars that are embedded within the structure. In the event of a proximate explosive detonation, such structures are ineffective in providing adequate protection because they disintegrate under blast pressure that may be in excess of thousands of pounds per square inch.

Description of Protective Structure

This paper describes a novel protective structure that minimizes the possibility that small pieces of concrete debris traveling at high velocity will escape the protective structure in the event of an explosion or blast load proximate to the structure.

As shown in Figures 1 and 2, the protective structure employs a membrane-like mesh structure made up of, for example, of steel wires. The mesh structure is compressible in all three dimensions, and surrounds a concrete fill material such as reinforced concrete. The size of the mesh opening is designed to retain the coarse aggregate constituent of concrete. In the event of an explosion, the mesh structure advantageously prevents concrete fragments produced due to disintegration of the concrete fill material from injuring people or causing property damage in the vicinity of the explosion.

The protective structure is capable of undergoing large deflections in response to an explosive loading, thereby absorbing the energy associated with the blast. The structure is sacrificial in nature: its sole purpose is to mitigate the blast effect of the explosion by preventing the escape of the disintegrated concrete debris and by absorbing the energy of the blast, thereby minimizing the loss of life and damage to property. After the explosion, the damaged structure will be dismantled and replaced with a new protective structure.

A number of the protective structure units can be joined together by columns or posts to create a wall of sufficient length to provide perimeter protection for a given area as well as additional
FIGURE 1 - FLEXI-WALL BLAST RESISTANT SYSTEM

FIGURE 2 - FLEXI-WALL REINFORCEMENT DETAIL
ease of construction and use. The interconnecting columns or posts also employ the mesh reinforcement structure in addition to conventional steel reinforcement bars.

It has been previously suggested [Conrath, 1999] that wire mesh may be employed on or just beneath the front and rear surfaces of the structural elements to mitigate “scabbing” (i.e. creation of craters on the target face due to a blast load) and “spalling” (i.e. separation of particles of structural element from the rear face at appropriate particle velocities) for light to moderate blasts loads. However, in the protective structure of this paper, the wire mesh structure employed does not merely mitigate scabbing and spalling for light to moderate blasts loads. Instead, the wire mesh structure can be designed to both prevent scabbing at large blast loads and to deflect elastically and plastically in response to the blast load to absorb the energy of the blast.

**Design Parameters of the Protective Structure**

The deflection of the protective structure may be analogized or modeled as wire in tension. Upon explosion and delivery of the blast load to the protective structure, the steel wires of the mesh structure deflect as they absorb the blast energy. Employing this model, the membrane stiffness of the mesh wire (K) is defined as

\[ K = \frac{P_e}{\Delta_e} \]  

where \( P_e \) is the load corresponding to the elastic limit of the wire mesh structure and \( \Delta_e \) is the deflection corresponding to \( P_e \), and the time period of oscillation of the wire mesh structure (T) in milliseconds is defined as:

\[ T = \frac{1000}{\omega} \]  

where \( \omega \) is the frequency of oscillations in cycles per second which is defined as:

\[ \omega = \left(\frac{1}{2}\pi\right)(K/m)^{1/2} \]  

where m is the mass per foot width of the mesh structure.

Using (1) through (3), various design parameters such as the wire gage, size of the mesh unit cell opening, steel grade, etc. may be selected for various blast loads, as set forth in Tables 1 and 2. The time period T is a critical design parameter. For a given blast event, it is expected that the time of duration of the blast will be in the order of a few milliseconds, say 5-10 milliseconds. Flowing well-established blast mitigation design practices [Conrath et al, 1999], the mesh structure should be designed such that it has a time period T much greater than the time of blast duration. Typically, T should be 10-20 times the duration of the blast.
### TABLE 1
Design Parameters for Flexi-mesh Structure (F_y = 36 KSI; L_m = 72 IN.)

<table>
<thead>
<tr>
<th>Wire Gage</th>
<th>Wire Diameter (in.)</th>
<th>∑A (in.²)</th>
<th>R_u (K)</th>
<th>P_e (K)</th>
<th>∆ (in.)</th>
<th>K (lb/in.)</th>
<th>m (lb-s²/in.)</th>
<th>ω (cps)</th>
<th>T (milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>0.062</td>
<td>0.290</td>
<td>10.44</td>
<td>1.09</td>
<td>3.77</td>
<td>289</td>
<td>0.0308</td>
<td>15.0</td>
<td>66</td>
</tr>
<tr>
<td>12</td>
<td>0.106</td>
<td>0.847</td>
<td>30.48</td>
<td>3.18</td>
<td>3.77</td>
<td>893</td>
<td>0.0899</td>
<td>15.0</td>
<td>66</td>
</tr>
<tr>
<td>10</td>
<td>0.135</td>
<td>1.373</td>
<td>49.44</td>
<td>5.16</td>
<td>3.77</td>
<td>1368</td>
<td>0.1458</td>
<td>15.0</td>
<td>66</td>
</tr>
</tbody>
</table>

Where
∑A is the sum of the area of the wires per foot width of mesh structure
R_u is the ultimate load capacity of the wire mesh per foot
F_y is the yield stress of the wire
L_m is the span of the wire mesh structure

### TABLE 2
Design Parameters for Flexi-Mesh Structure (F_y = 36 KSI; L_m = 72 IN.)

<table>
<thead>
<tr>
<th>Wire Gage</th>
<th>Wire Diameter (in.)</th>
<th>∑A (in.²)</th>
<th>R_u (K)</th>
<th>P_e (K)</th>
<th>∆ (in.)</th>
<th>K (lb/in.)</th>
<th>m (lb-s²/in.)</th>
<th>ω (cps)</th>
<th>T (milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>0.062</td>
<td>0.290</td>
<td>14.50</td>
<td>1.71</td>
<td>4.15</td>
<td>411</td>
<td>0.0308</td>
<td>18.4</td>
<td>54</td>
</tr>
<tr>
<td>12</td>
<td>0.106</td>
<td>0.847</td>
<td>42.35</td>
<td>4.99</td>
<td>4.15</td>
<td>1201</td>
<td>0.0899</td>
<td>18.4</td>
<td>54</td>
</tr>
<tr>
<td>10</td>
<td>0.135</td>
<td>1.373</td>
<td>68.65</td>
<td>8.08</td>
<td>4.15</td>
<td>1947</td>
<td>0.1458</td>
<td>18.4</td>
<td>54</td>
</tr>
</tbody>
</table>

Where
∑A is the sum of the area of the wires per foot width of mesh structure
R_u is the ultimate load capacity of the wire mesh per foot
F_y is the yield stress of the wire
L_m is the span of the wire mesh structure

### References