A Novel Cable-Enhanced, Wire-Mesh Reinforcement System for Structural Concrete to Improve its Blast-Resisting Properties

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Background Information

Conventional reinforced concrete structures typically employ steel reinforcing 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 are prone to disintegration under blast pressures that may be in excess of thousands of pound per square inch. Protection of people, buildings, bridges, etc. from car or truck bombs, remote controlled explosives, etc. is of increasing importance and necessity. It has been previously suggested [Conrath, 1999] that wire mesh may be employed on or just beneath the front and rear surfaces or inside 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 blast loads. It has also been previously suggested [Ahmad, 2008] that a wire-mesh reinforcement system not only prevents scabbing and spalling for light to moderate blasts loads but can be designed to deflect elastically and plastically in response to large explosive loads to absorb the energy of the blast.

Description of Proposed Protective System

This paper describes a novel reinforcement system for structural concrete to enhance its blast-resisting properties. The reinforcement system consists of (a) a mesh structure having an outer surface and an inner surface, wherein the inner surface defines an annular space (see Figure 1); (b) a plurality of thin structural steel cables in contact with the mesh structure (see Figure 1); (c) a composite fill material, such as concrete, which resides within the annular space of the mesh structure and within the mesh structure (see Figure 2); (d) at least one reinforcement member which resides within the composite fill material; and (e) a composite face material which resides upon the outer surface of the mesh structure. The mesh structure may be made up of, for example, steel wire. A protective system for protecting buildings, bridges, roads and other areas from explosive devices such as car bombs and the like comprises a plurality of the above described protective structures and a plurality of support members, wherein the support members provide interlocking engagement of the protective structures to the support members. A schematic diagram of two wall panels attached to either side of a column to form a perimeter protective wall using the cable-enhanced, wire-mesh reinforcement system is shown in Figure 3.
FIGURE 1: CABLE-ENHANCED, WIRE-MESH REINFORCEMENT SYSTEM FOR STRUCTURAL CONCRETE

FIGURE 2: WIRE-MESH REINFORCEMENT AND CONCRETE FILL

FIGURE 3: PERIMETER WALL CONSTRUCTION USING CABLE-ENHANCED, WIRE-MESH REINFORCEMENT
The mesh reinforcement structure surrounds, and is embedded in, a composite fill material such as conventional concrete or any of the other non-conventional concrete slurries currently on the market. The protective structure thus created is highly ductile and capable of undergoing large deflections and absorbing the energy associated with the blast pulse of an explosion while preventing the structure from disintegrating and causing shrapnel-like pieces to be launched in all directions resulting in personal injury or property damage. Figure 4 shows the deflected shape, generated by the software VISUALFEA, of a cable-enhanced, wire-mesh reinforced concrete wall subjected to a large normal blast pulse. The reinforcement system described in this paper is a significant improvement over conventional reinforced concrete that is prone to disintegration under explosive loads.

![FIGURE 4: SIMULATED DEFLECTED SHAPE OF A WALL PANEL UNDER BLAST PRESSURE](image)

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.

**Design Considerations for the Protective System**

The deflection of the protective structure may be analogized or modeled as a combination of wires and cables in tension. Upon explosion and delivery of the blast load to the protective structure, the steel wires of the mesh structure and the interwoven cables deflect as they absorb the blast energy. Employing this model, the membrane stiffness of the combination of the mesh wire and interwoven cables (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 $P_E$. The time period of oscillation of the wire mesh structure ($T$) in milliseconds is defined as:

$$T = \frac{1000}{\omega}$$  \hspace{1cm} (2)

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

$$\omega = \left(\frac{1}{2}\pi\right)(K/m)^{\frac{1}{2}}$$  \hspace{1cm} (3)

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, cable gage, steel grade, etc. may be selected for various blast loads (see Table 1). 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. Following well-established blast mitigation design practices [Conrath et al, 1999], the mesh structure and the interwoven cables should be designed such that the composite system 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>
<thead>
<tr>
<th>Wire Gage</th>
<th>$\sum A$ (in$^2$)</th>
<th>$R_U$ (K)</th>
<th>$P_E$ (K)</th>
<th>$\Delta$ (in)</th>
<th>$K$ (lb/in)</th>
<th>$m$ (lb-s$^2$/in)</th>
<th>$\omega$ (cps)</th>
<th>$T$ (milliseconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</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>0.847</td>
<td>30.48</td>
<td>3.18</td>
<td>3.77</td>
<td>893</td>
<td>0.0899</td>
<td>15.0</td>
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<tr>
<td>10</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
$\sum A$ is the sum of the areas of 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 1
DESIGN PARAMETERS OF WIRE-MESH STRUCTURE ($F_Y$=36 K/in$^2$; $L_M$=72 in.)

References