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# Modelling and simulation of earthquake resistant 3D woven textile structural concrete composites

Rajesh Mishra [a,*], Jiri Militky [a,**], Nishtha Gupta [b], Rajat Pachauri [b], B.K. Behera [b]

[a] *Department of Material Engineering, Faculty of Textile Engineering, Technical University of Liberec, 46117, Czech Republic*
[b] *Department of Textile Technology, Indian Institute of Technology Delhi, 110016, India*

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ABSTRACT

Concrete is a composite material composed of water, sand, coarse granular material called aggregate and cement that fills the space among the aggregate particles and glues them together. Conventional building structures are made up of steel skeleton with concrete impregnation. These are very heavy weight structures with steel vulnerable to corrosion. The conventional concrete structures tend to undergo large deformations in the event of a strong earthquake. Mechanical simulation of various textile structural concretes is carried out successfully for their ductility behaviour. 3D woven reinforced concretes display superior ductile character showing ray of hope to develop seismic resistant building. Simulation of three 3D woven fabrics and their composites was carried to predict ductility and strengths of fabric reinforced concrete structures. Maximum deformation was observed for beam reinforced with orthogonal interlock fabric under the same load and minimum deformation was observed for plain concrete. Maximum equivalent stress was observed to be highest for plain concrete followed by beam reinforced with angle interlock fabric followed by orthogonal fabric and warp interlock fabric under similar loading conditions. From the results it was clear that 3D fabric reinforced structures are more ductile than the traditional steel reinforced structures. Hence 3D fabric reinforced concrete structures are much better in strength and ductility as compared to conventional construction materials. Among the three 3D fabric, orthogonal fabric reinforced composites are most ductile and are also less stiff. They can deform more than the other two fabric composites. Hence, orthogonal fabric reinforced composites can undergo higher deformations without collapsing. These composites can be more elastic under earthquake shaking.


## 1. Introduction

Concrete is a composite material composed of water, sand, coarse granular material called aggregate and cement that fills the space among the aggregate particles and glues them together. Conventional building structures are made up of steel skeleton with concrete impregnation. These are very heavy weight structures with steel vulnerable to corrosion. Most of the conventional concrete structures tend to undergo large deformations in the event of a strong earthquake. If the stresses caused due to lateral forces experienced by the structures exceed its strength, the structure yields, if it is ductile. If the structure is brittle, as in the case of unreinforced masonry, it will suffer brittle failure. The pattern of failure of masonry buildings during an earthquake makes it clear that the prevention of sudden flexural failure of masonry wall is critical to ensure an earthquake resistant masonry structure. Earthquake is seismic vibration which generates ground motion both in horizontal and vertical directions as shown in Fig. 1. Due to the inertia of the structure this ground motion generates shear stress and bending moment in the structural framework. In earthquake resistant design it is important to ensure ductility in the structure, i.e. the structure should be able to deform without causing failure. Conventional concrete looses its tensile resistance after the formation of multiple cracks. So, the joints need to be more ductile to efficiently bear or dissipate the seismic forces. Hence it is desirous that the building materials be ductile and have large deformative capacity which would make the building shake without mangling. It is also desired that the building materials be low in weight, so the lives under rubble after building falls down,

* Corresponding author. Tel.: +420 48535 3209.
** Corresponding author.
*E-mail address:* rajesh.mishra@tul.cz (R. Mishra).

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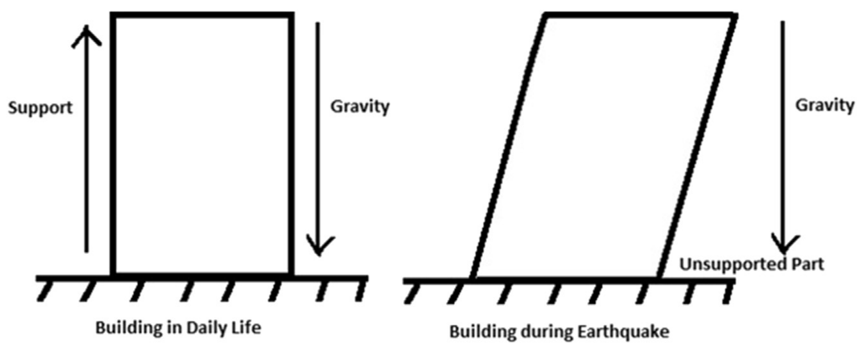


**Fig. 1.** The movement of building during earthquake.

have more chances of escape and recovery. Introduction of some innovative textile structures in concrete framework can provide substantial protection to the building collapse due to seismic force.

Hence researchers all over the world have been working on fibre/textile reinforced concrete composite structures, especially for earthquake resistant buildings as they are light in weight and strength: weight ratio is much higher than the traditional materials [1]. Many researchers have carried out experiments to examine the advantage of fibrous material in concrete either in discontinuous randomly oriented fibre form or continuous unidirectional form [2–4]. However, it is well known that textile technology facilitates development of numerous structures which can have varied mechanical properties as regard to their compressive, flexural and ductility behaviour. In this research, efforts are made to model several textile structural concrete on Solidworks and predict their mechanical characteristics simulating some seismic stress conditions on the structures in Ansys platform. The modelled results are validated against some experimental findings.

## 2. Materials and methods

### 2.1. Materials

The properties of the fibre used is given in Table 1.

The structures of 3D woven fabrics are made on standard weaving machine with small adjustments. The main purpose of preparation of 3D fabrics was to use it as reinforcement component in composite preparation. To study the effect of fabric structure on composite properties total 3 different 3D fabrics were prepared. Approximately equal areal density of 3 different 3D woven fabrics is maintained to isolate the effect of fibre content. While preparing the yarn for weaving, a special surface finish was given to avoids defibrillation. Fabric structures developed are given in Table 2.

Table 3 shows the properties of concrete used (Table 4).

#### 2.1.1. M10 concrete composition

IS 456 has designated the concrete mixes into a number of grades such as M10, M15, M20, etc. In this designation, M denotes the mix and the number denotes the 28 day cube strength of mix in N/mm$^2$. The mix of grade M10 correspond approximately to the mix proportions (1:3:6).

**Table 2**
Reinforcement structures used for simulation.

| Reinforcement type | Warps/cm | Wefts/cm | Fibre volume fraction (%) |
|---|---|---|---|
| Orthogonal fabric | 4 | 3 | 40.3 |
| Warp interlock fabric | 7 | 8 | 46.6 |
| Angle interlock fabric | 4 | 3 | 40.2 |
| Chopped fibre | – | – | 38.6 |

**Table 3**
Properties of M10 concrete.

| Property | Value | CV% |
|---|---|---|
| Density (kg/m$^3$) | 2398 | 6.34 |
| Young's modulus (MPa) | 15,811 | 5.12 |
| Poisson's ratio | 0.15 | 3.24 |
| Compressive ultimate strength (MPa) | 10 | 6.95 |
| Tensile strength (MPa) | 2.2 | 3.73 |

### 2.2. Methodology

#### 2.2.1. Modeling of textile structures

Textile structures in the form of three different 3D woven solid structures such as orthogonal, angle interlock and warp interlock structures and discontinuous randomly oriented fibres as shown in Fig. 2a–d are modelled on SolidWorks platform [5–7]. These structures are used as reinforcement with standard concrete M10 in the form of beam. One plain concrete with similar composition and geometry is also developed for comparison purpose. These concretes are subjected to flexural loading in a mechanistic simulation on Ansys platform as shown in Fig. 2e. The deflection of the beam is shown in Fig. 2f. Deformation of all the structures along with stress

**Table 1**
Properties of glass fibre.

| Property | Value | CV% |
|---|---|---|
| Density (kg/m$^3$) | 2540 | 4.52 |
| Young's modulus (MPa) | 67,170 | 6.32 |
| Poisson's ratio | 0.3 | 5.02 |
| Compressive ultimate strength (MPa) | 1450 | 5.65 |
| Tensile strength (MPa) | 2150 | 4.45 |

**Table 4**
Concrete mix design.

| Ingredient | Amount |
|---|---|
| Cement | 210 kg/m$^3$ |
| Sand | 824 kg/m$^3$ |
| 10 mm aggregate | 473 kg/m$^3$ |
| 20 mm aggregate | 707 kg/m$^3$ |
| Water | 186 kg/m$^3$ |