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A systematic study on composite materials in civil engineering

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ABSTRACT

In this paper, a brief and applied study is performed for reviewing the application of composite materials in civil engineering structures and presenting the significant results and methods based on recent research (as an appropriate short-cut). Some applied trusses and algorithms, related simulations, bridge analysis, and applied solved problems are presented and analyzed in this article. For example, one of the dangerous and undesired happenings is failure and fracture in the structures, which may occur for the buildings. Therefore, the composite behavior must be accurately investigated for predicting and preventing unpleasant hazards. Thus, the analysis and application of the composites in the structures are essential and require increasing the safety and lifetime as well as suitable for managing the time and costs. Moreover, some highlighted challenges for the use of composites in the future such as considering costs and environment management are presented. Finally, a simulation has been done for simplifying the real problem to simple geometrical engineering system in section 6 (solved problems) which would be useful for engineers and students (researchers).

1. Introduction

Recently, composites are growing in civil engineering structures, automotive and other usages owing to many of their benefits. We can explain "past, present and future" of composite materials with an example. We can divide the history of carbon fibers and CFRPs to three periods including their primary development and growth of carbon fiber composites industry (past: 1970–2010), major adoption of carbon fiber composites (present: 2010–2020) and expanded use of carbon fiber composites (2020-20XX). Lower cost carbon fibers like large tow and associated manufacturing technologies are frequently changing. Lastly, the consequences of emerging materials and manufacturing methods along with recycling and reuse for carbon fiber composites with considering environment, economic will be discussed more in the future. Lots of studies were done to forecast the manner of the composite's materials in the civil engineering field. For example, high strength against the crack propagation and failure or fracture is the most important advantage of the composites [1–4]. Some advantages and benefits of the composites in civil engineering and structures are including the suitable and high strength, strength against the crack propagation and chemical reactions, lightweight and high strength simultaneity, high strength against impact, corrosion resistance, design sustainability, flexibility, and durability, as well as long life [1,3].

Reinforced materials (composites) are typically classified by the kind and type of material utilized for the matrix generally. Overall, four initial classifications of composites are polymer-matrix-composites (PMCs), metal-matrix-composites (MMCs), ceramic-matrix-composites (CMCs), and carbon-matrix-composites (CAMCs) [1–3].

Fibrous (short/long) composites are one of the important sections of the paper. So, I added a definition section. In fibrous (short/long) composites, the fiber embedded in resin, held in place by the resin (matrix), contributes tensile strength, increasing performance properties in the final part, like final strength and stiffness, while diminishing related weight accordingly. Fiber-reinforced polymer composite FRPC presents high strength to weight ratio, exceptional properties like high durability, suitable stiffness, excellent damping property, flexural strength, and corrosion resistance, wear, impact, and sometimes fire [2–7].

Also, a particle reinforced composite is described as being composed of particles embedded in a resin or matrix. Particles may have almost any special shapes, desired sizes, or many configurations. Particle reinforced composites find applications where high levels of wear resistance are needed like some road

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surfaces. Also, the hardness of cement is enhanced meaningfully by adding gravel as a reinforcing filler logically [1,3–8].

For example, a novel thought on crack propagation, damage, failure, and fracture has been developed together with new nondestructive assessment techniques by various researchers. Materials engineering science has been essential to overcome the misfit between the dissimilar classes of the material such as "metal-ceramic", "polymer-ceramic", and "bio-based matrix-natural fibers". For another instance, for the reinforced polymer composites PMC's, carbon-based fillers, as fibers and carbon allotropes, recover and strongly improve the mechanical and electrical properties of the composite materials practically [63,64]. This allows the design of lightweight composite buildings, constructions, and structures with embedded functions, such as heating or sensing capabilities to screen crack propagations, deformations, loadings, damage, failure and fractures as well as fatigue. Recently, in addition to the obvious characteristics of the composites, interesting topics have been highlighted by many researchers about the analysis and design of the reinforced structures like the use of the keywords of application of "machine learning ML and artificial intelligence AI","piezoelectric materials", "sensors", and "hybrid bridges" in this fields [1–38,52,54–56].

So, analyzing and application of the composites in the structures are essential and required to increase the safety and lifetime. Which, one of the important highlights of this research article is the application of the geometrical and theoretical solution methods and problem solution steps (algorithms, flowcharts) in analyzing the real composite structures and doing the simulation of those. Finally, selected and applied algorithms and research works have been selected and presented in this research article for optimizing and saving the time (and costs) of the researchers for finding the suitable methods quickly. It should be mentioned that some applied and interesting results and methods have been presented in this paper.

Composite structures and constructions are related to two load-carrying structural members [1,28]. Composite structures provide an approach of utilizing two or more materials together to use each material to its best benefit [62]. In addition, fiber-reinforced plastic composites (FRPC's) are recently employed in extensive applications in structures and constructions, owing to the different advantages they prepare over traditional building substances. Lighter substances also make easier handling along with assembly, decreasing installation value [53]. Tables 1, and 2 present the nomenclature and abbreviation used in this research article.

One of the important aims of this research work is the short and selected reviews of many articles as well as simulation of the real problems with simple geometrical problems (see section 5: solved problems). The following flowchart may show briefly the steps and framework of the paper (Fig. 1).

In the future, some important challenges are including sustainable composite materials and their toxicity analysis, compatibility with environment, carbon issues, green composite materials in circuit board design, procedure optimization of synthesis of green composite materials, building composite materials from bio-sourced, recycled materials; waste resources, and their combinations, and as well as economic aspects and criterion.

2. General information

The mechanical attributes of the related composites are popular with everybody. As the reader will display, lots of composites are not boosted by continuous fibers but by short fibers.

In this part, some models for the mechanical manner of short fiber composites are identified. Numerous applications of the fiber–matrix-composites were known to employ in structural engineering like civil engineering, that is, their application in the construction will grow until ultimately, they will take their place along with steel and concrete as key engineering materials shortly. Reinforced materials will not substitute the traditional materials

Table 1
Nomenclature and description of the scientific symbol.

Nomenclature Scientific Symbol	Description, Unit, Address
E	Young's modulus (Pa), Fig. 3
G	Shear Modulus (Pa), Fig. 3
L	Member Length (m), Fig. 3
I	Cross Section Moment of Inertia (m^4), Fig. 3
A	Section Area or Total Area (m^2), Eqs. (1,2), Fig. 3
A_s	Equivalent Shear Area (m^2), Fig. 3
R_j	Post-Elastic Rotational Bending (N.m), Fig. 3
T_j	Transverse Shearing (Pa), Fig. 3
N_j	Normal Axial Stiffness of the Member at the Two End Sections, (N/m) j = 1, 2, Fig. 3
r_j	Bending Stiffness Degradation Factors, (N/m), Fig. 3
t_j	Shearing Stiffness Degradation Factors, (N/m), Fig. 3
n_j	Axial Stiffness Degradation Factors, (N/m), Fig. 3
M	Applied Bending Moment (N.m), Eqs. (1,2)
V	Shear Force (N), Eqs. (1,2)
A_w	Web Area (m^2), Eqs. (1,2)
M_y	Initial-Yield Capacity, Bending Moment (N.m), Eqs. (1,2)
V_y	Initial-Yield Capacity, Shear Force (N), Eqs. (1,2)
M_p	Full-Yield Capacity, Post-Elastic/Plastic Bending Moment (N.m), Eqs. (1,2)
V_p	Full-Yield Capacity, Post-Elastic/Plastic Shear Force (N), Eqs. (1,2)
P	Axial Force (N), Eqs. (1,2)
A_d	Debonding Area (m^2), Eq. (3)
A_t	Total Bonding Area (m^2), Eq. (3)
f_d	Defective Specimen in each mode, Eq. (4)
f_i	Intact Specimen in each mode, Eq. (4)
d_e	Distance of a Center of Defect from a Free End (m), Eq. (5)
d_i	Total Length (m), Eq. (5)

Table 2
Abbreviation used in the article.

Abbreviation Scientific Symbol	Description
BSS	Bone-Shaped Short
FRPC	Fiber Reinforced Plastic Composite
CSS	Conventional Straight Short
MEKP	Methyl Ethyl Ketone Peroxide
RVE	Representative Volume Element
RSA	Rivest–Shamir–Adleman
FRGC	Fiber-Reinforced Geopolymer Composite
UHPFRC	Ultra High-Performance Fiber-Reinforced Concrete
FE	Finite Element
GNP	Graphite Nanoplatelet
APM	Alternate Path Method
GSA	General Service Administration
RCC	Reinforced Concrete
HSS	Hollow Structural Section
DFT	Defects Face Truss
DTM	Defects Truss Missing
DFW	Defects Face sheet Wrinkling
DGR	Defects Gap Reinforcing
FRF	Frequency Response Function
CFS	Cold-Formed Steel
PSSC	Profiled Steel Sheeting-Concrete
ALC	Autoclaved Lightweight Concrete
CFRP	Carbon Fiber Reinforced Polymer
CSWs	Corrugated Steel Webs
NDE	Non-Destructive Evaluation
DCR	Demand Capacity Ratio

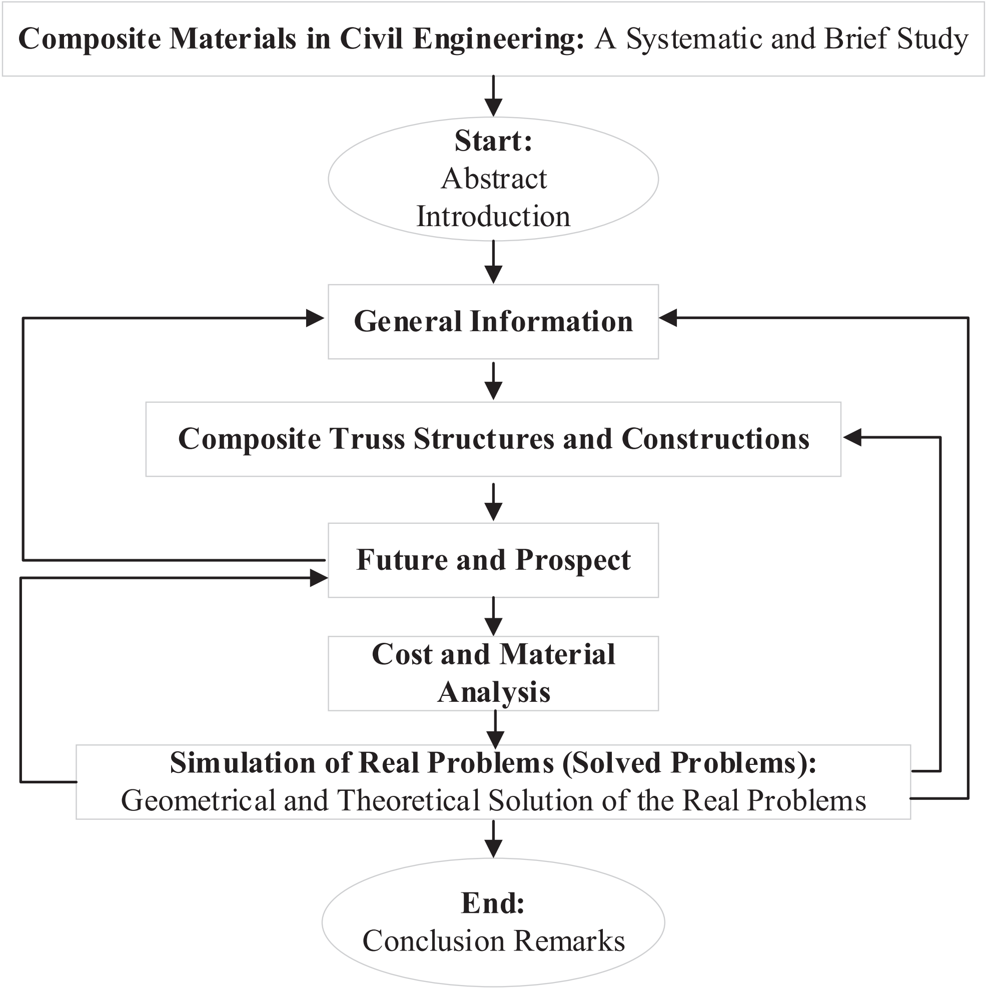


Fig. 1. A framework and flowchart of this review article.

but then will develop an essential part of the structural engineer's materials selection soon [1,2].

Composite/reinforced trusses may be suitable for greater strength and stiffness compared the composite girder systems, making them more appropriate for long-span applications and column-free ranges. Additionally, the composite and reinforced trusses may be optimized for various projects, giving the engineer better and larger design flexibility when compared to catalog girders. For example, the designer may choose HSS or angle sections for the top and bottom chords. That is, it is significant to select the material accessibility when designing composite trusses with the purpose of costs may be diminished through employing readily obtainable sections and cautiously choosing chord and web members. That is, applying a cautious design-assist method with fabricator coordination will diminish time and costs (optimizing time, costs, and workers).

For new structures, the main challenge lies in the development and design of new sustainable, green (bio-compatible), high strength, lightweight, multi-functional structural materials (high compatibility with environment, CO_2 emissions) and related manufacturing methods.

3. Composite truss structures and constructions

Here, as a graphical and schematic instance, the stress–strain behaviors of conventional straight short (CSS) Ni-fiber composite and BSS Ni-fiber composites are depicted in Fig. 2a-c [3]. The strength of CSS-fiber composite samples is smaller than BSS-fiber composite samples. So, the dimension of the tensile sample and DCB specimen are respectively depicted in Fig. 2a,b. 4-point bending tests have been done on steel wire reinforced cement (see Fig. 2c).

The average strength of the BSS (bone-shaped short)-fiber composite samples makes better by 10.2% [3] (see Fig. 2(d)). Fig. 3 displays the algorithm of the periodic RVE generation following the altered RSA procedure graphically [4,52]. The mentioned flowcharts and algorithms may create approximately up to $\sim$ 15% volume fractions with the equal fibers generally. Now, the equal fibers are considered only and the created periodic RVE and mesh of composites are reinforced by the spatially arbitrarily dispersed fibers with the aspect ratios of $\sim$ 15 and fiber volume fraction of $\sim$ 10% (see Fig. 3).

The versatility of lightweight composite materials, their strength-to-weight ratios, and their stiffness-to-weight ratios have made them highly desirable in civil engineering. It has become possible to confidently use these substances due to various behavioral aspects similar to the failure of composites [5,6]. Also, a novel lightweight sandwich panel manufactured with PUR foam core and fiber-reinforced geopolymer composite (FRGC) skin layers for making buildings have been presented [6].

It should be mentioned that the applied and important study works were utilized about the failure/fracture examines of the composites in the civil engineering fields and structures/buildings/mechanical devices by various investigators in recent years [7–23]. For example, a progressive-failure examination process

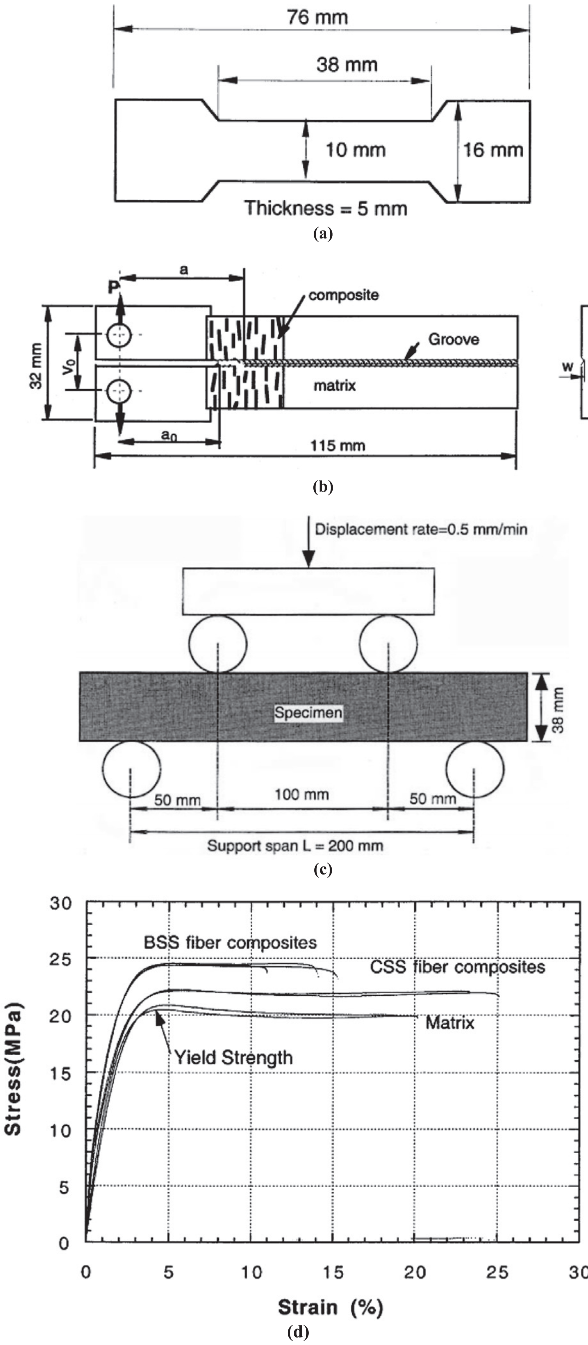


Fig. 2. (**a**)- Geometry of test composite sample for tensile testing (**b**)- Drawing of the DCB sample (**c**)- Format of the 4-point bending flexural test (**d**)- Straight short Ni fiber composites and polyester matrix and stress–strain curves of bone-shaped. Ni fiber length = 2.5 mm, diameter = 76.2 m. Fiber volume fraction = 1.7% [3].

has been introduced to assess the efficiency of a building framework after it is destroyed by unexpected, unusual loading. Based on Fig. 4, for the planar beam-column part: L = member length, A_s=equivalent shear area, G = shear modulus, A = section area, E = Young's modulus, and I = cross section moment of inertia; as well, as the parameters T_j, R_j, and N_j are respectively transverse shearing, normal axial stiffnesses, and the post-elastic rotational bending of the member at the two end sections j = 1, 2. Also, t_j, r_j, and n_j are called shearing, bending and axial stiffness degradation parameters (beam-column member has been modeled in Fig. 4) [3].

By combining bending moment M and the shear force V, the initial yielding of a member section is organized by the normalized first-yield criterion,

$$\left(\frac{V_y M_p}{V_p M_y}\right)\left(\frac{M}{M_p}\right)+\left(\frac{V}{V_p}\right)=\left(\frac{V_y}{V_p}\right) \qquad (1)$$

Also, the full yielding of the section is obtained to be organized by the normalized full-yield criterion [24].

$$\left(\frac{M}{M_p}\right)+C_1\left[1-\sqrt{1-\left(\frac{V}{V_p}\right)^2}\right]=1 \qquad (2)$$

Hence, $C_1 = A_w/(2A - A_w)$ for a wide flange steel section having a web area A_w (e.g., $C_1 = 0.2$ when $A_w = A/3$) and total area A [7]. Following the present method, all the internal mesh boundaries are considered as potential crack segments, modeled as cohesive interfaces equipped with a properly calibrated mixed-mode traction-separation law to account for nano-reinforcements' toughening influence [20]. In Fig. 5, the axial stress distribution along the tensile reinforcement bars of the three simulated UHPFRC beams is recorded.

A final indication of the capability of the embedded truss model to accurately describe stress transfer between concrete and steel phases is the oscillation behavior of these stress values as well as the local maxima that are located near completely developed local minima and cracks that are between two contiguous cracks. Still, a whole confirmation of the current method is out of the scope of this research study [20], owing to the limited amount of data accessible in the previous literature, to the authors' best science [20].

In addition, the investigation of analytical methods to assess progressive collapse has been done using linear static evaluation via the Alternate Path Method (APM), and the same has been introduced and presented [18]. This research [18] aims to determine if the columns in a composite building are vulnerable to progressive collapse by removing columns from various locations. Which, the situation of the number of floors, the removed column, and vertical irregularity have been studied (see Fig. 6, 7(a)-(d)). It should be mentioned that progressive failure and collapse study of a reinforced building of "G + 7″ floors is done considering steel beam, and steel column with RCC slab. These building plans and structural promotion are respectively depicted in Fig. 6, 7a-d. The size and dimension of the beam are ISMB 300, and column sizes are ISMB 600. Also, "B1-7″ are beams connected with a column "C1-4″.

Here, in the corner column of the removal model, the applied load of the removed column is transferred to the adjacent column and the maximum bending moment is detected to happen in beams B1 and B4. In the side column removal model, an applied load of the removed column is transferred to the adjacent column in the neighborhood of that column and the maximum bending moments are seen in the beams B1-B3. So, It should be mentioned that the structural elevation of the building is related to the model 1 (Fig. 7a), model 2 is related to the corner column removal model (Fig. 7b), and model 3 is associated with the interior column removal model (Fig. 7c), and model 4 indicates the side column removal model (Fig. 7d).

At last, one of the dangerous happenings in the structures is the buckling of the plates and columns investigated in the references [25,26].

A composite (reinforced materials) truss is a steel truss manufactured from rolled sections and a matrix. The composite truss structures may be fitted for better endurance, strength, and stiffness than the other similar truss structures without composite materials. In addition, the composite trusses structures may be customized for any construction project [59].

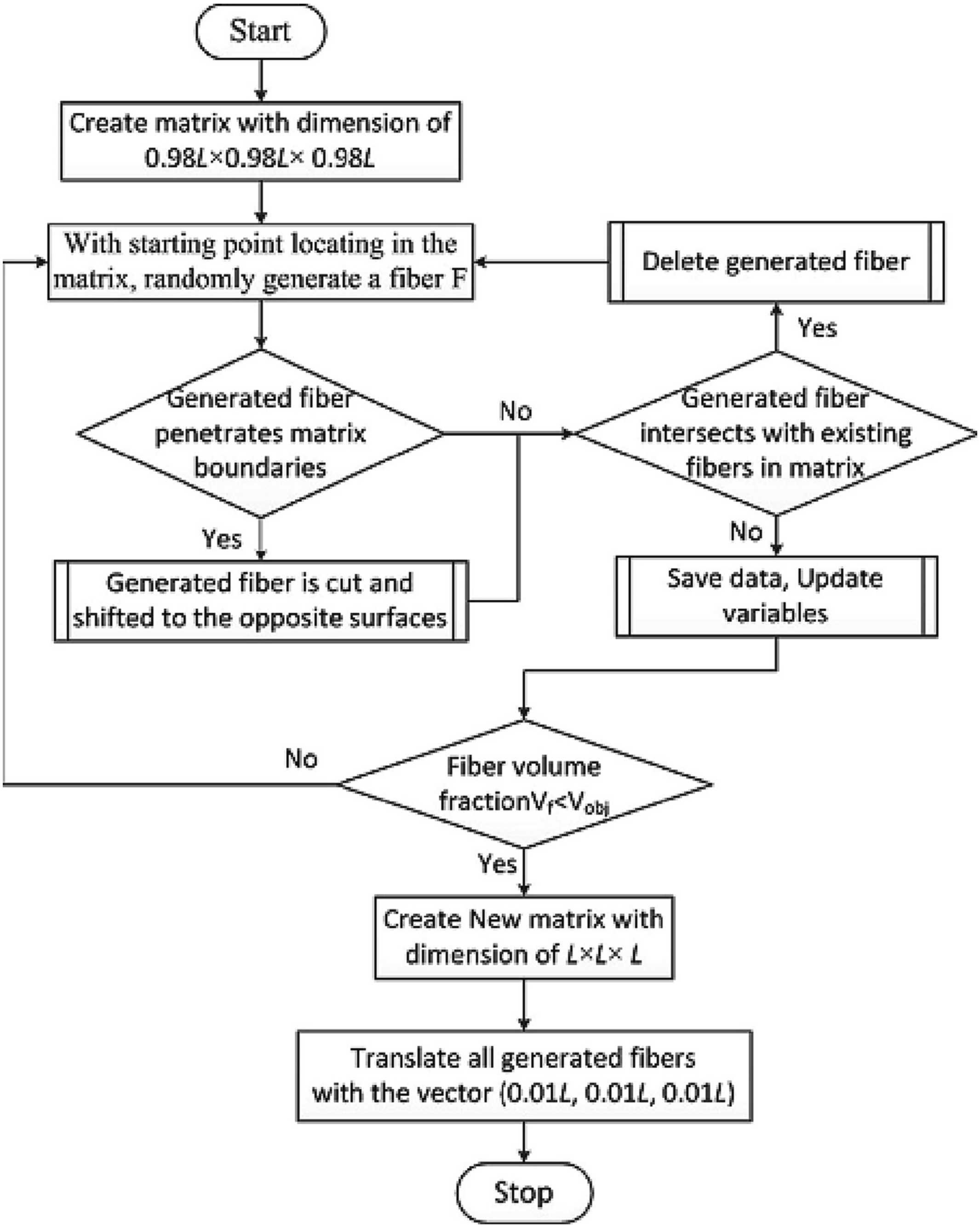


Fig. 3. Algorithm of the periodic RVE generation according to the altered RSA algorithm [4,52].

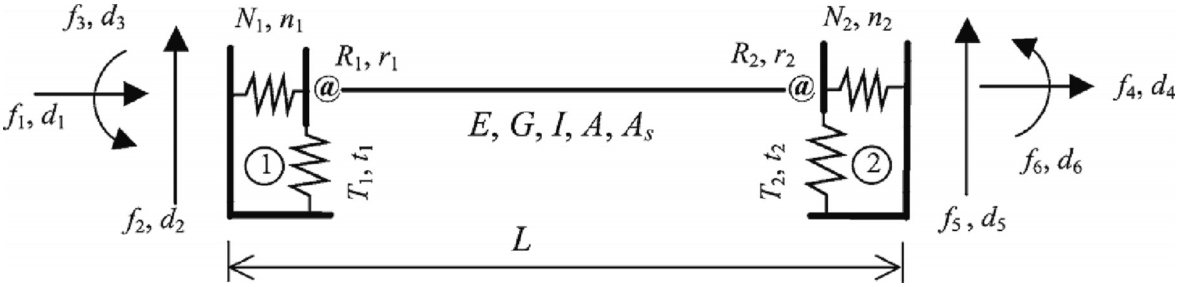


Fig. 4. Beam-column member model [7].

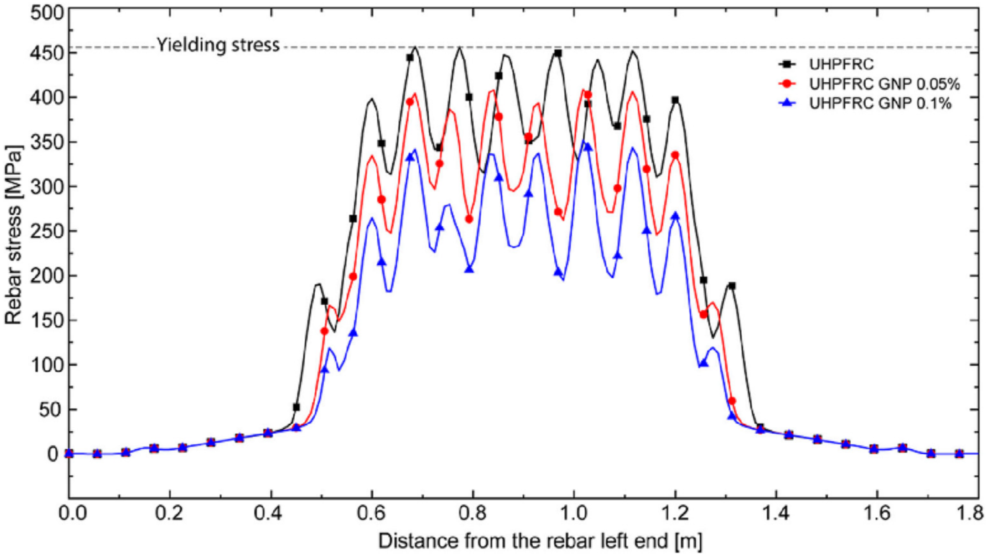


Fig. 5. Axial stress distribution along the tensile longitudinal reinforcement bars of the three considered UHFRC beams for a load level of 65 KN [20].

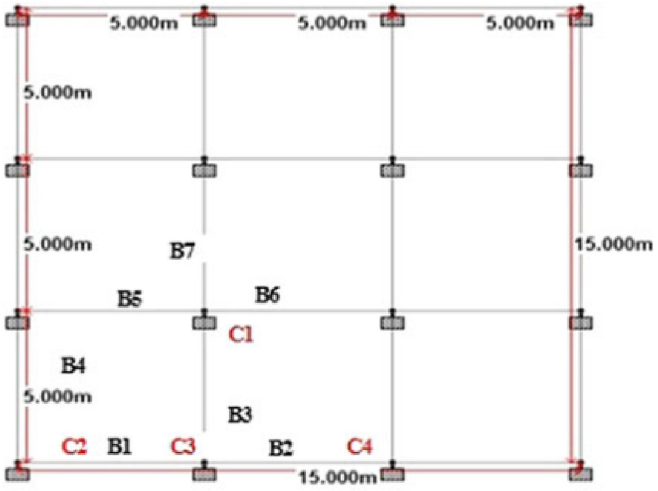


Fig. 6. Plan of the building [18].

A designer and engineer can choose the truss pattern like Vault, Pratt, Hip, double cantilever, Warren, and changed Warren most suitable for the space of mechanical structures and ducts and electrical services as needed (Fig. 8,9 [27,53]). Suppose the normal openings of the composite trusses constructions need on-site change. In that case, reinforcement may be applied fully simply.

For example, for bridges and other structures and constructions, plane trusses are commonly applied in pairs, with one truss assembly placed on each side of the structure. A section of classic bridge construction has been depicted in Fig. 9. For example, the Warren truss is a general design for both actual and model (simulation) bridges in the world. The Warren truss employs equilateral triangles to distribute the applied loads on the bridge. Fink trusses originated as bridge trusses and are generally used in residential homes and bridge architecture, though their present use in bridges is rare. A Howe truss is a truss bridge including the chords, verticals members, and diagonals members whose vertical members are in the state of tension and whose diagonal members are in the state of compression. A Pratt truss comprises vertical members and diagonals which slope down towards the center, the opposite of the Howe truss. In which, the interior diagonals are subjected to the tension under balanced loading and vertical elements under compression effects. In the Pratt truss the intersection of the verticals and the lower horizontal tension members are utilized to anchor the supports for the short-span girders subjected to the tracks.

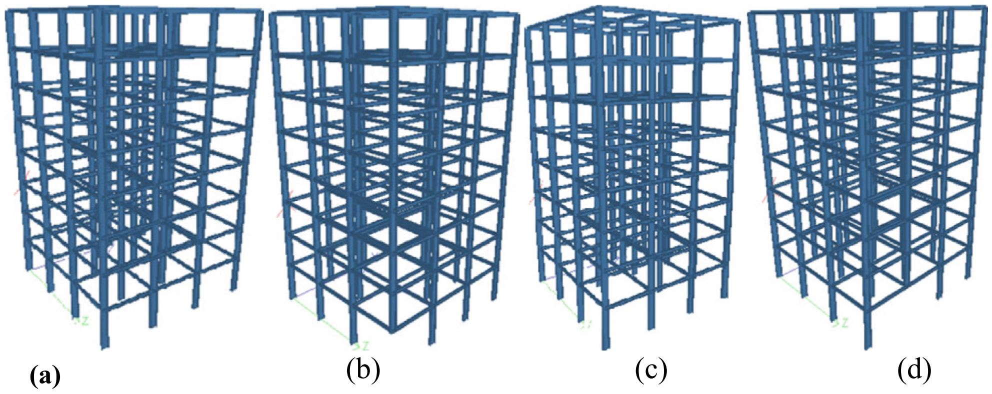


Fig. 7. **(a)-** Structural elevation of the building (model 1), **(b)-** Corner column removal model (model 2), **(c)-** Interior column removal model (model 3), **(d)-** Side column removal model (model 4: side column removal model) [18].

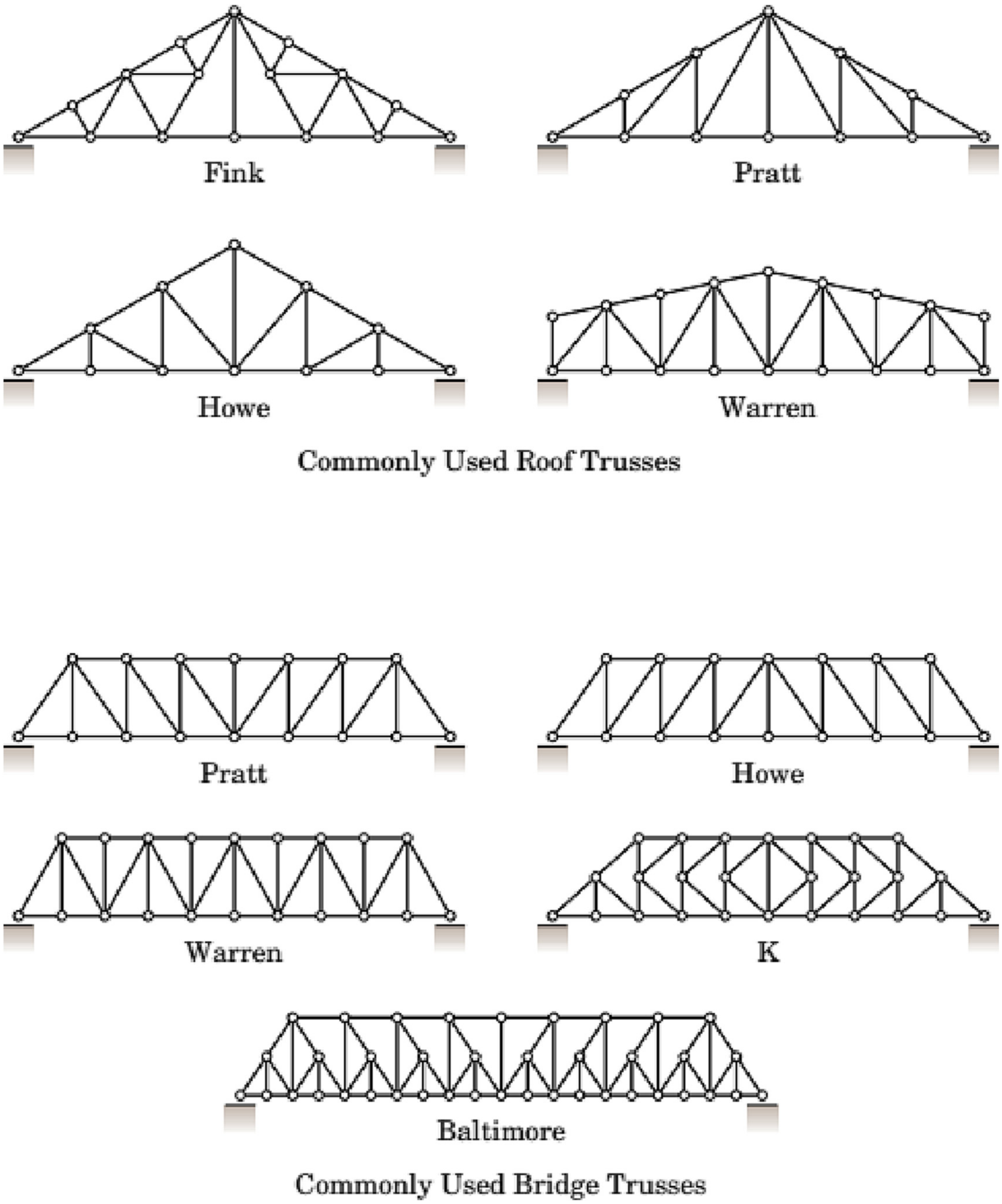


Fig. 8. Classic truss patterns and samples [27].

The Baltimore truss is a subclass of the Pratt truss. A Baltimore truss has further bracing in the lesser section of the truss to avoid buckling in the compression members and to control deflection. It is mostly employed for rail bridges, showing off a simple and very robust design. The K-truss is named after the K formed in each panel by the vertical member and two oblique members. The idea of the K-truss is to break up the vertical members into smaller sections. This is because the vertical members are in the state of compression effects. The shorter a member is, the more it can resist buckling from compression. The K-truss, undoubtedly owing to its complication, did not become a favorite in the world.

Experimentally some types of truss bridge samples are the strongest. The Pratt and Howe designs are two of the most used truss bridges. Howe Bridge was designed to minimize the maximum compression force.

Several examples of usually applied trusses that can be investigated as plane trusses are displayed in Fig. 8 [27].

Some research works investigating the composite truss structures and constructions are introduced and studied shortly [29–47]. Which, many researchers have analyzed the sandwich structures [29–33,48], bridge structures [34–38], and other important works regarding Composite truss structures and constructions [39–51].

For instance, the manufacturing defect sensitivity of the composite pyramidal truss-like core sandwich cylindrical panels' modal characteristics has been studied using numerical and experimental simulations. Defects containing the debonding between truss cores (DFT) and face sheets, face sheet wrinkling (DFW) truss missing (DTM), and gap reinforcing (DGR) have been presented in

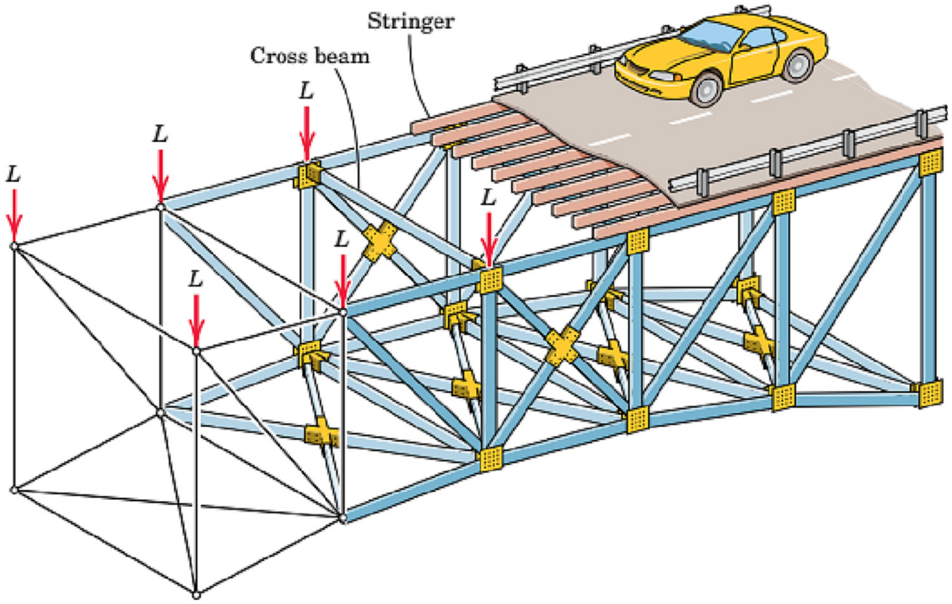


Fig. 9. Applied truss structure sample [27].

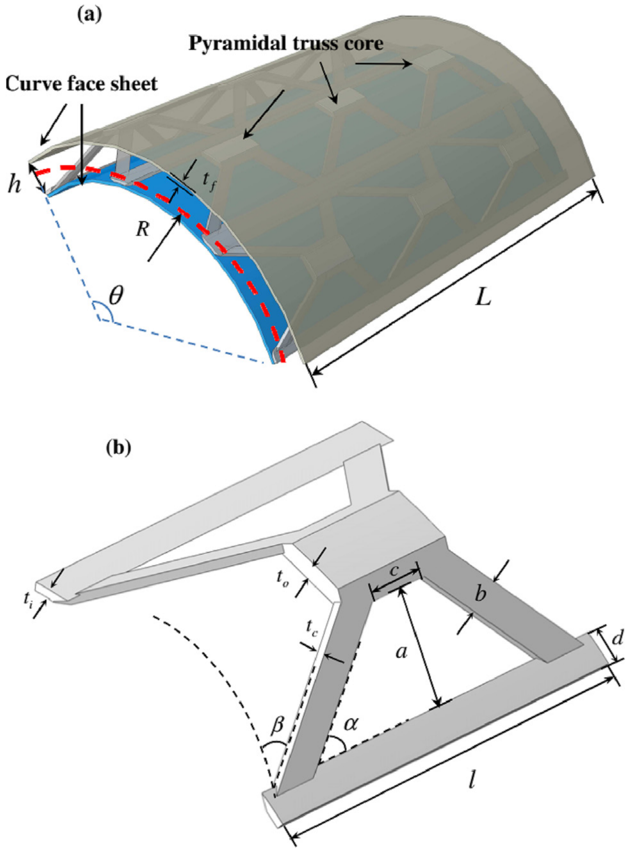


Fig. 10. (a)- The diagram of composite pyramidal truss-like core sandwich cylindrical panel, **(b)-** representative cell of pyramidal truss-like core [31].

this study. To calculate the defect degree and extent, a defect coefficient κ is introduced by the following,

$$\kappa = \frac{A_d}{A_t} \times 100\% \tag{3}$$

For the DFT, A_t and A_d respectively present the total bonding region and the debonding region. For the DTM,A_t and A_d are respectively the total number of the intact trusses and the number of missing trusses. In the pyramidal truss-like core sandwich cylindrical panels the relative variation of frequencies λ is presented by,

$$\lambda = \frac{f_d - f_i}{f_i} \times 100\% \tag{4}$$

Where f_i and f_d respectively present the intact and defective specimen [31]. The location of δ_i in the Y or X direction are displayed in Fig. 11(a) is determined as,

$$\delta_i = \frac{d_e}{d_i} \times 100\% (\mathrm{i} = \mathrm{X}, \mathrm{Y}) \tag{5}$$

Where d_i and d_e are the distance of a center of defect from the total length and a free end. Fig. 10 depicts the intact composite sandwich cylindrical panel geometry with 3 × 3 pyramidal truss-like cores. The geometrical factors are $L = 156mm$, $R = 58mm$, $\theta = 108^{\circ}$, $h = 11mm$, $t_f = 1mm$, $a = 12.7mm$, $b = 4mm$, $c = 5.1mm$, $d = 3.8mm$, $l = 50.14mm$, $t_o = 1mm$, $t_i = 1mm$, $t_c = 0.5mm$,$\beta = 60^{\circ}$ and $\alpha = 45^{\circ}$. The relative density of the core is 3.16% [31].

The evaluations of the natural frequencies of defective and intact composite pyramidal truss- have been explained and shown in Fig. 11. The locations and extents of damaged regions with DTM and DFT are shown in red color. There is less than 14.6% error in the simulations compared to the investigations [31].

Fig. 12 shows the comparisons of the specimen's frequency response functions (FRFs) without and with imperfections. Fig. 12a-f depicts and describes the comparisons of frequency response functions, FRFs, of the specimen with/ without faults especially. The amplitudes of "FRFs" are diminished with the enhancing the fault extent and even may significantly decrease by approximately 32.7 dB compared with the intact mentioned specimen commonly. The obtained results illustrate that the mentioned specimen with DFW and DGR intensely decreases the amplitudes of "FRFs", with a small reduction of the fundamental frequencies generally.

Imperfections may become visible in the composite lattice truss core sandwich constructions and structures throughout the complex preparation procedure, considerably affecting the structural

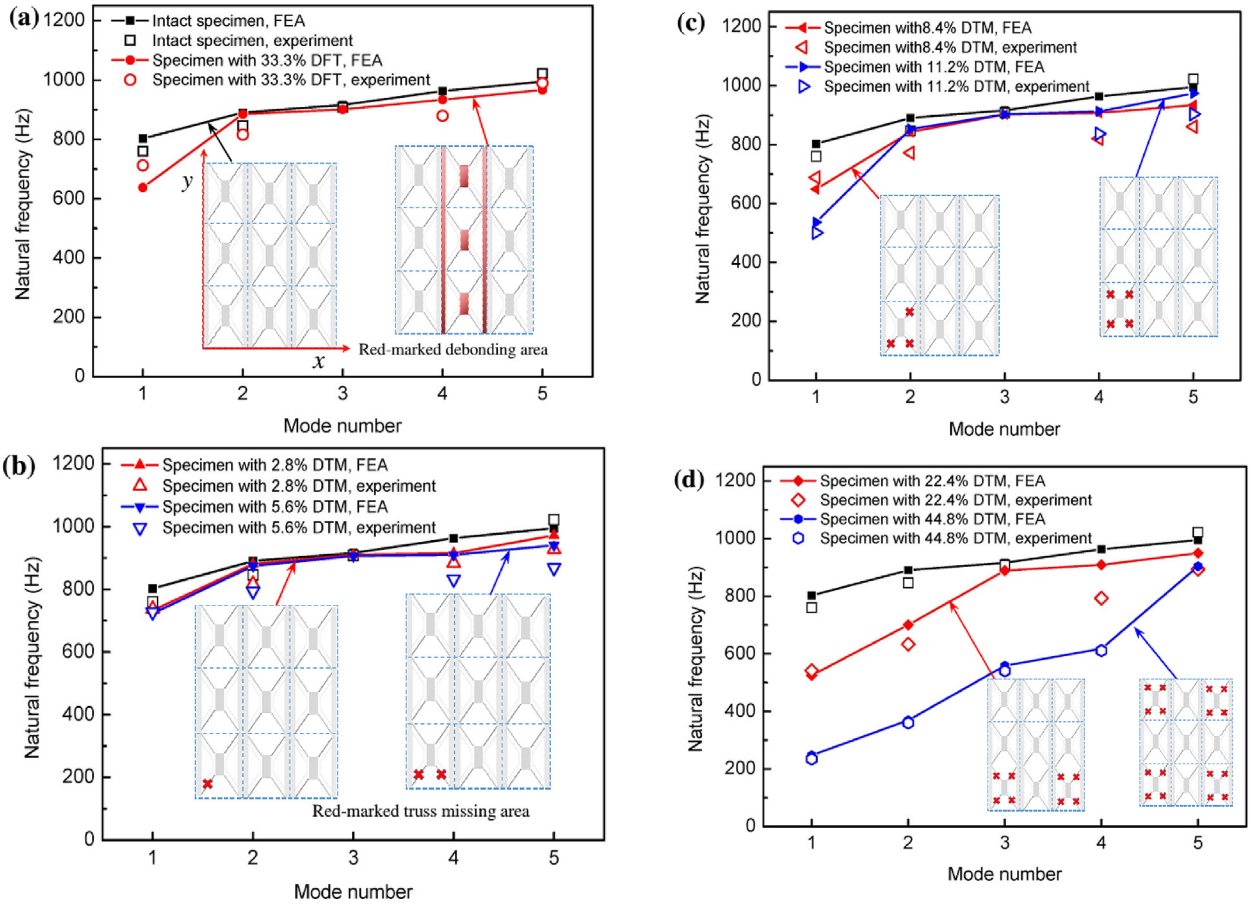


Fig. 11. Comparisons of natural frequencies of intact and defective composite pyramidal truss-like core sandwich cylindrical panels [31].

answers and reducing the load-carrying capability. It depends primarily on the modes of vibration, the extent, location, and form of imperfections in the present sandwich cylindrical panels [31]. For example, a short and simplified model to compute the initial stiffness and shear bearing capacity of cold-formed steel (CFS) truss composite floor with profiled steel sheeting-concrete (PSSC) slab has been presented. The obtained results can provide a reference to better the suitable usage of this kind of composite floor in applied engineering sciences [47].

A cold-formed steel CFS composite floor with a profiled steel sheeting-concrete PSSC slab has been presented [47]. This kind of composite floor consists of the CFS truss beam, concrete slab, and profiled steel sheet, as depicted in Fig. 13. Consequently, a series of tests on the CFS composite floor was conducted. The CFS truss composite floor constructions with ALC or PSSC slabs are presented and depicted in Fig. 14 [47].

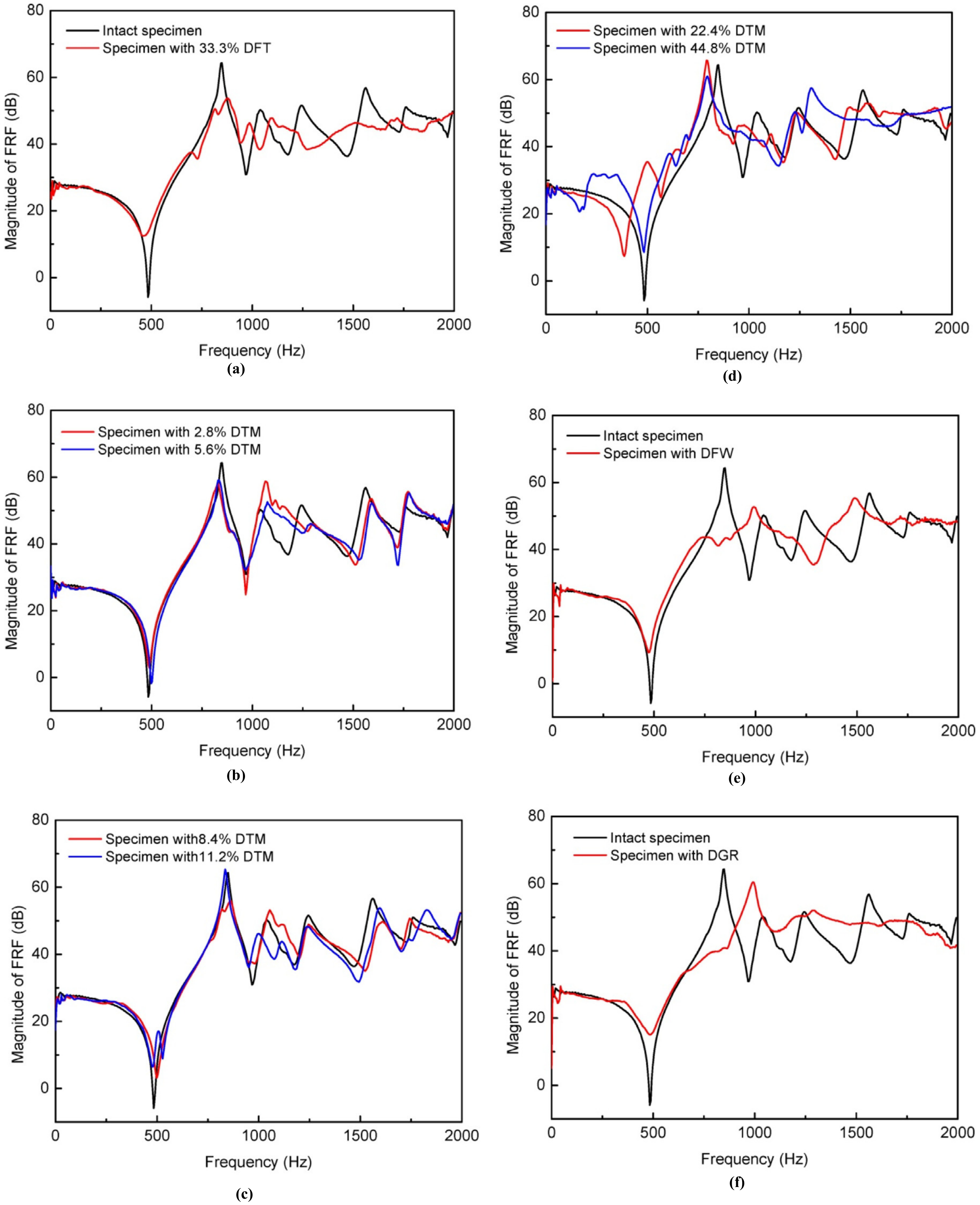
Also, mechanical responses of the sandwich beams with tailored hierarchical honeycomb cores were studied under a three-point bending load [48]. In which, equivalent bending stiffness and bending strength were determined and investigated. As well, the strengthening mechanism of each tailored hierarchical structure was revealed. Briefly, the study of [48] is studying on bending performance of a sandwich beam with tailored hierarchical honeycomb cores. Mathematical model of the equivalent bending stiffness was used the proposed hierarchical sandwiches subjected to three-point bending. Bending strength was involved to investigate the bending behaviors. In addition, parametric studies have been done for sandwiches with diverse tailored hierarchical cores for exploring their influence on the hierarchy effect.

Also, the composite package girder bridge with corrugated steel webs (CSWs) and trusses (recently presented bridge construction and structure) have been presented. Moreover, two applied engineering instances containing a footbridge and a viaduct have been illustrated precisely with details in [34]. The flexural manner of this kind of construction and structure has been studied experimentally [34]. Applying this type of bridge can satisfy the requirement of fast structure and cost-saving, so it is value being promoted worldwide. The simplicity of maintenance, low cost, and minimizing the self-weight of the structure are some advantages of using this kind of bridge. Moreover, this construction and structure (scaled model of the Maluanshan Park Viaduct) present superior integrity and ductility subjected to flexural load when appropriately designed. The flexural deformation may be separated into an elastic stage, an elastoplastic stage, and a plastic stage. The cross-section can still be regarded as a plane part at the elastic stage when only the top concrete slab and the bottom steel tubes are remarked (see Fig. 27).

Fig. 27 displays the measured load–deflection curve of the test beam. So, according to the investigational obtained results prove “Maluanshan Park Viaduct” will normally work within the elastic limitation once it is under the enduring and inconstant applies loads specified in the engineering design guideline accordingly (see Fig. 27).

4. Future and prospect

The core structural analysis and design, impact loading response, material type and potential applications of the sandwich structure continue to grow and advance using mathematical (theoretical, analytical), experimental, and simulation approaches soon. It is a problem and challenging mission to extensively



(a) (d) (b) (e) (c) (f)

Fig. 12. Experimental frequency response functions (FRFs) of intact and faulty reinforced pyramidal truss-like core sandwich cylindrical panels, curve of "Magnitude of FRF" vs. "Frequency", comparing for **(a)-** intact specimen and specimen with 33.3% DFT **(b)-** specimen with 2.8% DTM and specimen with 5.6% DTM **(c)-** specimen with 8.4% DTM and specimen with 11.2% DTM **(d)-** specimen with 22.4% DTM and specimen with 44.8% DTM **(e)-** intact specimen and specimen with DFW **(f)-** intact specimen and specimen with DGR [31].

enhance the application prospect and commercial markets because of the costs and manufacturing and fabrication method [33]. With attention to the development of manufacturing technology, we must find new methods and approaches to solve and analyze difficulties and problems to get new achievements and desired outputs. It should be mentioned that the sandwich panels and structures have a high potential to employ many engineering applications like tissue engineering (scaffolds, Lung, organs on chips, Kidney, skin, vessel), biomedical, which, have presented many promising areas for further applications and suitable prospects.

Shortly, the long-span high-speed railway bridges will progressively assist the tolerable development of the general economy and society, along with the implementation of nationwide strategies like the Belt and Road Initiative. In which, we can hope to develop the high-speed railway in the next years. Finally, in addition to

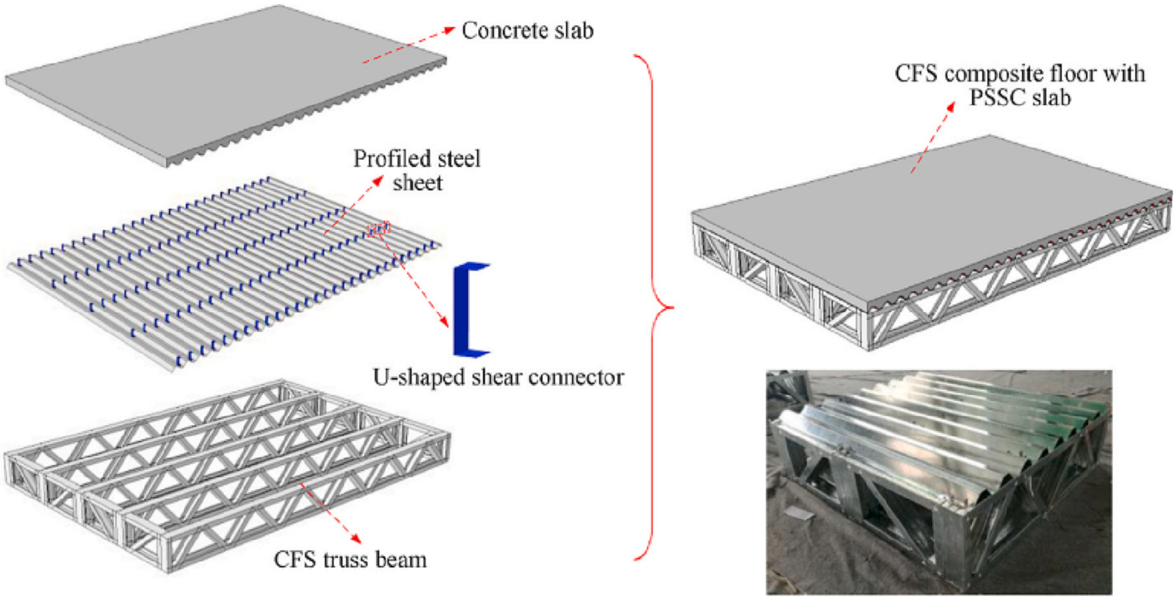


Fig. 13. CFS composite floor with PSSC slab [47].

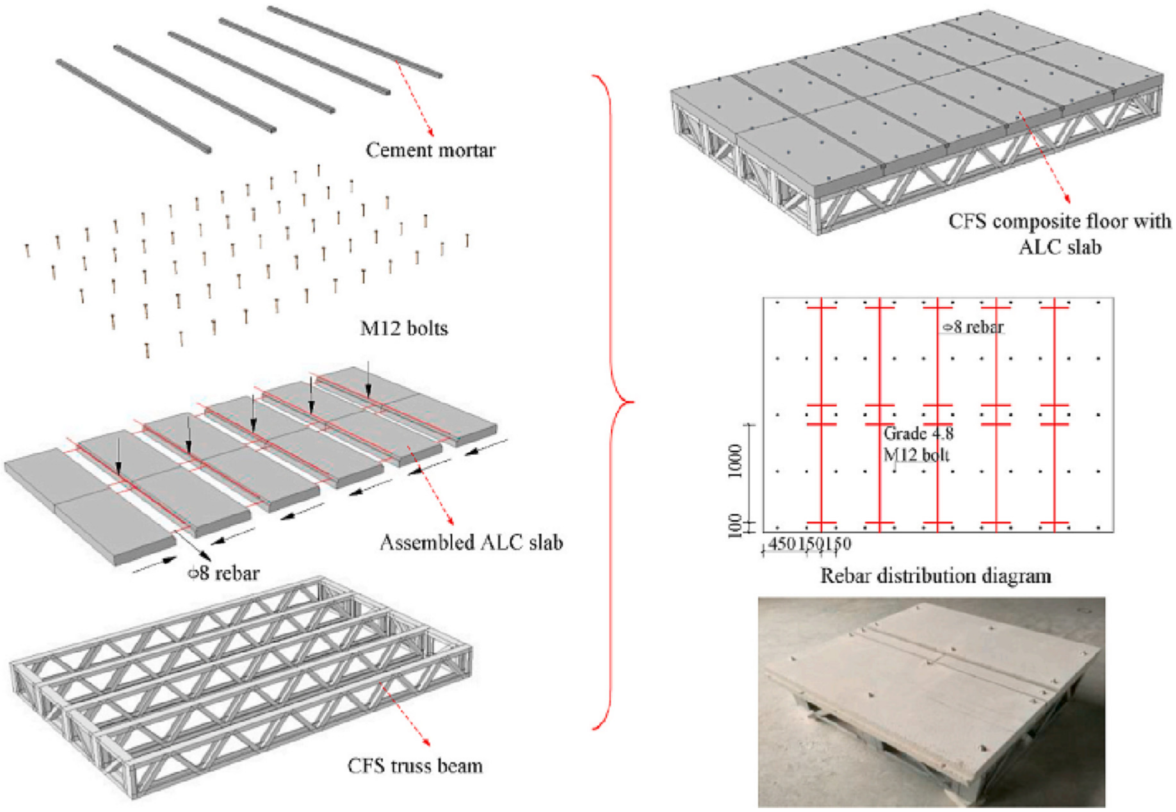


Fig. 14. CFS composite floor with ALC slab [47].

advanced industries, the nice prospect of composite structures can develop and extend for the application in tissue engineering, biomechanics, organ-on-chip, vessels, sensors, and scaffolds.

5. Cost and material analysis

Composites and nanocomposite devices and structures are sensitive to damage throughout the manufacturing and also are sensitive to fatigue rupture, creep failure, crack propagation, and degradation during related services. So, the cost of inspection, maintenance and repair are highly important and affect design strategies. That is, they are some critical criteria for the design and manufacturing of nanocomposites. For example, creep in composites or nanocomposites is a very dangerous event that affects the quality of materials. This unpleasant creep phenomenon may cause to create and establish some microcracks and ruptures [57]. Also, degradation in composites/nanocomposites may be resulted in the fully collapse of the structure and increase the cost of repair and maintenance. So, exact designing the composites with considering the crack, degradation, optimized weight, suitable strength, and creep criteria can be very useful to prevent increasing the cost and sometimes save time and cost.

Composite materials have become equivalent to innovation and modernity which affect to our daily lives, from everyday objects to health facilities, the construction of modern sewer networks, and storage reservoirs, to intricate structures automotive, smart composite structures, planes, and space science (shuttles and turbine blades). So, nanocomposites have had significant growth in care because of their characteristics, suitable durability, excellent strength, reduced energy usage during the manufacturing process, and diminished transportation costs. Briefly, if the composite/-nanocomposite structure and bridge is built in a standard instruction and correctly used, it will be cost-competitive with some concrete bridges with small and medium support spacing and steel bridges with support spacing up to $\sim 120\ m$ [58].

Although composite and nanocomposite materials are now considered original, they have been widely employed for more than 80 years. They are often composed of polymeric materials that have been reinforced with glass or sometimes carbon fibers. It was seen that the life cycle of these goods is often longer than their efficiency, which is sometimes seen as a negative rather than a profit since ecological integrity needs operative recycling. There are restricted options to dispose of the non-biodegradable glass fiber-based composites. They may be recycled into lower-grade goods, burned for energy recovery, or disposed of in a landfill. Unfortunately, the most cost-effective approach and method of removal at the moment, and hence the selected method, is landfill storage. It should be mentioned that bio-composites will convert a main of most people's lives when novel, undeveloped bio-composites and more well-organized manufacturing technologies become accessible [59–61]. Bio-composites will be utilized in more and more areas of our life because of their accessibility and low-priced cost.

Generally, concrete is the most common artificial composite material of all and classically contains loose stones, and aggregate, held with a matrix of cement. Also, fiber-reinforced polymers comprise a carbon-fiber reinforced polymer and glass-reinforced plastic. For instance, fiberglass is plastic that is combined with glass fibers. Likely, your bathtubs, doors, decking, and window frames all take advantage of fiberglass in some ways.

Carbon fiber may be employed to strengthen steel, concrete, masonry and some timbers. Carbon-reinforced polymer rebar is an enormously robust and light alternative to steel rebar and is utilized in most bridge decks, some parking structures, and other engineering applications that are susceptible to corrosion phenomena and magnetic fields. Moreover, polymer rebars are not thermally or electrically conductive generally. Also, carbon fiber-reinforced polymer compounds have been utilized to build and construct footbridges since the 1990 s. The advantages of carbon-polymer over ordinary concrete comprise less weight and longer life. Manufacturers started embedding carbon fiber into the precast concrete (2003). Replacing steel mesh in the concrete makes the concrete lighter and more durable logically. It also allows less use of concrete, reducing weight and cost [66].

The use of a different resin polyfurfuryl alcohol (PFA) is an amazing breakthrough for composite interior panels, in some structures. This bearable resin is derived from biomass waste, and may in the future replace the oil-derived resins currently used for some applications. Employing PFA in place of phenolic prepregs avoids the need to work with harmful chemicals, like free formaldehyde and phenols, making the resin more user-friendly and healthier for the environment. Also, PFA-based sandwich panels may hurt from a diminished skin-to-core bond strength, which has been compensated for by optimizing cure parameters and utilizing cautiously chosen secondary adhesives [65]. It should be mentioned that there are three most common bridge material options are fiber-reinforced polymer (FRP), steel, and wood. Some of the chief materials found on a bridge are including steel, concrete, stone and asphalt as well as thin steel strands. Other materials comprise iron, timber, aluminum, rubber and other joint materials. Prestressed concrete decreased the amount of steel and concrete required in construction and structure, resulting in lighter designs that are often less expensive than designs of reinforced concrete. Steel (carbon steel, high-strength steel, and heat-treated carbon steel) is extensively employed around the world for the construction of bridges from the very large to the very small.

Some requirements are essential to the use of composite materials in novel structures and constructions applications as the following,

- Considering creep, microcrack, crack propagation control, degradation analysis
- Logical selection of the materials and suitable processing/manufacturing methods
- Using novel methods for predicting some parameters via machine learning
- Suitable secondary manufacturing processes
- Adequate manufacturing base
- Developing the design and life prediction methods
- Effectiveness of non-destructive assessment methods
- Competitive life cycle costs
- Economic analysis, suitable lifetime, time management, excellent mechanical properties, periodical inspections, frequent repair and maintenance, and correct and engineering material selection

Finally, six new and different materials that are changing commercial construction are as the following [67],

- Mass Timber
- Self-Healing Materials
- Air Cleaning Bricks
- Strand Rods
- Passive Cooling Ceramics
- Trash

6. Solved problems

Here, the applied and interesting problems are solved and analyzed in the field of structures and trusses. These solved problems may be beneficial for analyzing the composite trusses in civil engineering.

6.1. Problem a

P.5.1. Obtain the related forces in the following members of DN and DM of the symmetric loaded composite truss in a bridge using the method of joints (see Figs. 15-18).

Solution.

The method of joints to find the forces in the members of a composite truss includes satisfying the conditions of equilibrium for the forces acting. The present approach deals with the equilibrium of simultaneous forces, and only two self-governing equilibrium equations are engaged. To solve this problem, first of all, joint "E" is analyzed and considered for finding EM and DE without obtaining the external reactions at A and I. That is,

Joint E

$$\theta = arctan\frac{24 - 24sin60^{\circ}}{24\sin 30^{\circ}} = 15^{\circ} \tag{6}$$

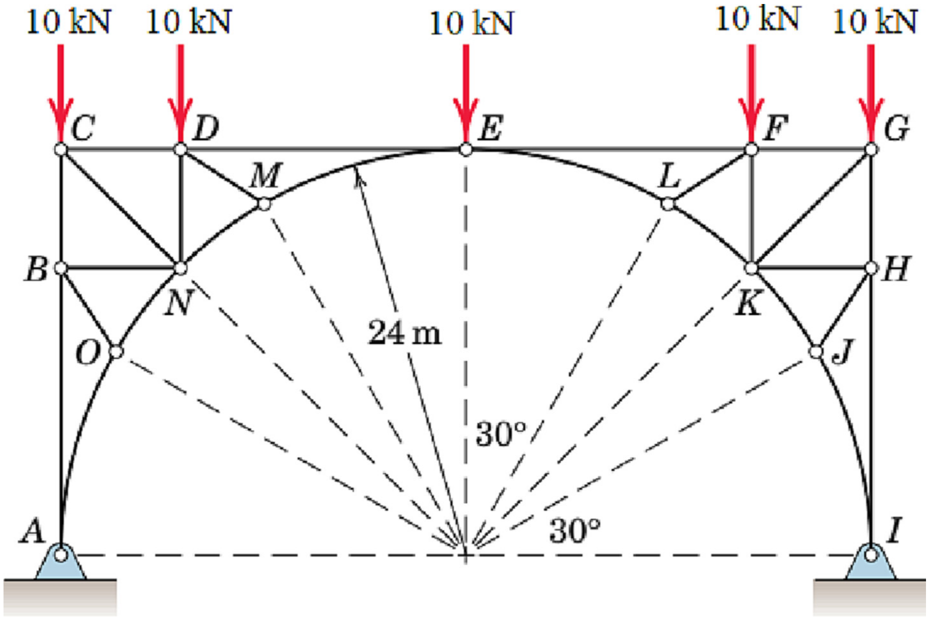


Fig. 15. A composite bridge with members [27] (with minor changes).

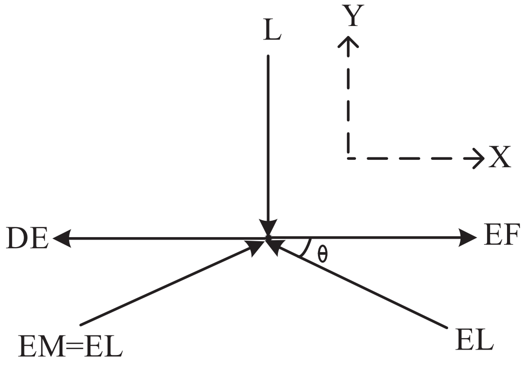


Fig. 16. Joint E.

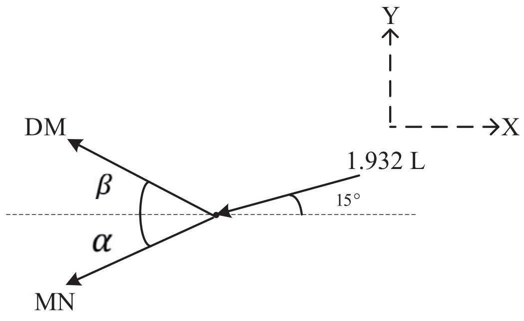


Fig. 17. Joint M.

According to the equilibrium equation have,

$\sum F_y = 0 \rightarrow 2\left(EM \times \sin 15^\circ\right) - 10 = 0 \rightarrow$ EM = 19.3 kN (Compression) (7).

$\sum F_x = 0 \rightarrow 19.3 \times 10 \times \cos 15^\circ - DE = 0 \rightarrow$ DE = 13.6 kN (Tension) (8).

Joint M

$$\alpha = \arctan \frac{24 \sin 60^\circ - 24 \sin 45^\circ}{24 \cos 45^\circ - 24 \cos 60^\circ} = 37.5^\circ \tag{9}$$

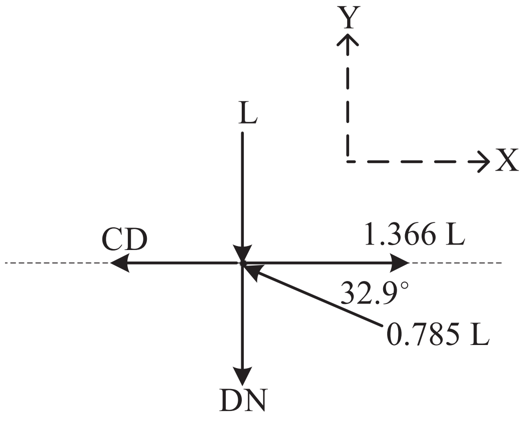


Fig. 18. Joint D.

$$\beta = \arctan \frac{24 - 24\sin 60^\circ}{24 \cos 45^\circ - 24\cos 60^\circ} = 32.9^\circ \tag{10}$$

Following the equilibrium equation,

$$\sum F_x = 0 \rightarrow -DM \times \cos 32.9^\circ - MN \times \cos 37.5^\circ - 19.3 \times 10 \times \cos 15^\circ = 0 \tag{11}$$

$$\sum F_y = 0 \rightarrow DM \times \sin 32.9^\circ - MN \times \sin 37.5^\circ - 19.3 \times \sin 15^\circ = 0 \tag{12}$$

With concurrent solving the above equations have,

$$DM = 7.8kN(\text{Tension}) \tag{13}$$

Joint D

$$\sum F_y = 0 \rightarrow 7.8 \times 10 \times \sin 32.9^\circ - DN - 10 = 0 \tag{14}$$

So yields,

$$DN = 5.7kN(\text{Tension}) \tag{15}$$

6.2. Problem b

P.5.2. Find the force in the members of "FG" and "*GK*" of the loaded symmetrical reinforced truss using the method of sections (see Fig. 19,20).Fig. 20.Fig. 21.Fig. 22.Fig. 23.Fig. 24.Fig. 25.Fig. 26.

Solution.

Once we analyze the composite plane trusses through the joints approach, we require only two of the three equilibrium equations. The approach of sections has the fundamental benefit that the force in almost any desired member may be found straightforwardly from an analysis of a section that has cut that member. In choosing a section of the truss, generally, not more than three members whose forces are unknown should be cut since there are only three obtainable self-governing equilibrium formulations and relations. Because of the symmetry in geometry and loading and using the equilibrium equation in the y-direction, the reactions at A and I are as the following,

$$A_y = H_y = 30kN \tag{16}$$

Also,

Using equilibrium equation in x-direction,

$$A_x = 0 \tag{17}$$

By some simple geometrical calculations, the following locations (m) are obtained, that is,

$$B = (9, 23.3), J = (6, 24.3), G = (6, 29.3), K = (3, 24.8) \tag{18}$$

$$\alpha = \arctan\frac{29.3 - 24.8}{3} = 56.3^{\circ} \tag{19}$$

$$\beta = \arctan\frac{24.8 - 24.3}{3} = 10.39^{\circ} \tag{20}$$

Again the equilibrium equation (momentum) yield,

$$\sum \mathrm{M_k} = 0 \rightarrow 3 \times 10 \times 6 - 5 \times 6 + FG(29.3 - 24.8) - 30 = 0 \tag{21}$$

So have,

$$FG = -26.6kN(Compression) \tag{22}$$

$$\sum F_x = 0 \rightarrow 26.6 - GK\cos 56.3^{\circ} - JKcos10.39^{\circ} = 0 \tag{23}$$

$$\sum F_y = 0 \rightarrow 15 + JKsin10.39^{\circ} - GKsin56.3^{\circ} = 0 \tag{24}$$

With concurrent solving the above equations have,

$$GK = 21.3kN(Tension) \tag{25}$$

6.3. Problem c

P.5.3. Achieve the force in member "CL" of the loaded composite truss.

Solution.

Because of the symmetry in geometry and loading and using the equilibrium equation in the y-direction, the reactions at A and H are as the following,

$$A_y = H_y = 30kN \tag{26}$$

Also,

Utilizing equilibrium equation in x-direction,

$$A_x = 0 \tag{27}$$

By some simple geometrical computations, the following locations (m) are obtained, that is,

$$B = (-15, 26), A = (-18, 20), C = (-9, 28.6), M = (-9, 20), D = (-3, 29.8), L = (-3, 20) \tag{28}$$

$$\alpha = \arctan\frac{29.8 - 28.6}{6} = 11.6^{\circ} \tag{29}$$

$$\beta = \arctan\frac{28.6 - 20}{6} = 55.2^{\circ} \tag{30}$$

Again the equilibrium equation (momentum) yield,

$$\sum \mathrm{M_L} = 0 \rightarrow (-3 \times 10 \times 15) + (10 \times 6) + (10 \times 12) - CD(29.8 - 20)\sin(90^{\circ} - 11.6^{\circ}) = 0 \tag{31}$$

So yields,

$$CD = -27.9kN(Tension) \tag{32}$$

$$\sum F_y = 0 \rightarrow 30 - 10 - 10 - 27.9sin11.6^{\circ} - CLsin55.2^{\circ} = 0 \tag{33}$$

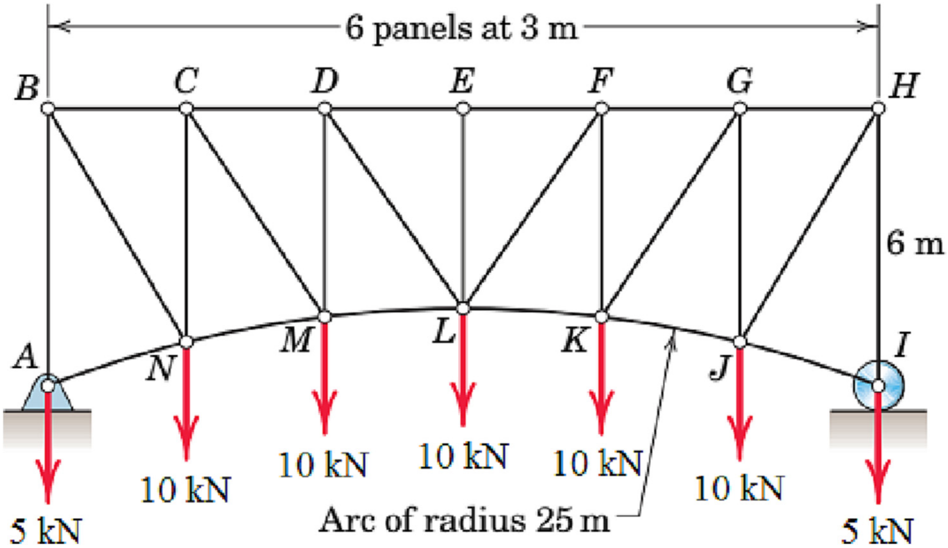


Fig. 19. A reinforced bridge with members [27] (with minor changes).

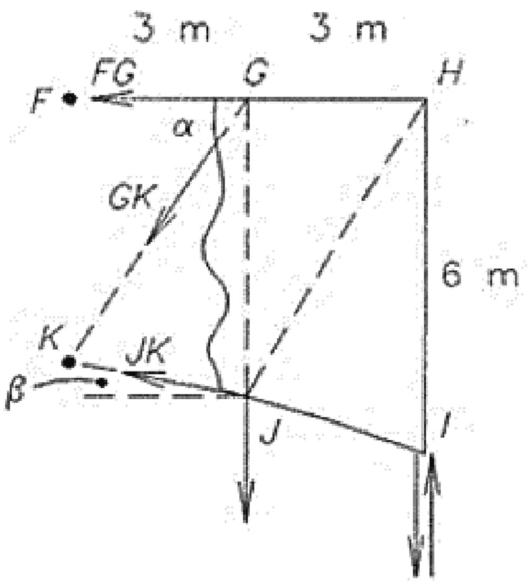


Fig. 20. Sections at the members of GK, FG, and JK.

$$CL = 5.34kN(Tension) \tag{34}$$

6.4. Problem d

P.5.4. Buckling evaluation of the bridge section depicts that the vertical composite truss members can support 525 kN in compression, the horizontal composite truss members can support 300 kN in compression, and the diagonal truss members can support 180 kN in compression.

Solution.

Because of the symmetry in geometry and loading and using equilibrium equation in the y-direction, the reactions at A and G are as the following,

$$A_y = G_y = 5L \tag{35}$$

Also,

Utilizing equilibrium equation in x-direction,

$$A_x = 0 \tag{36}$$

It is obvious that,

$$F_{AB} = F_{FG} = 5L(Compression) \tag{37}$$

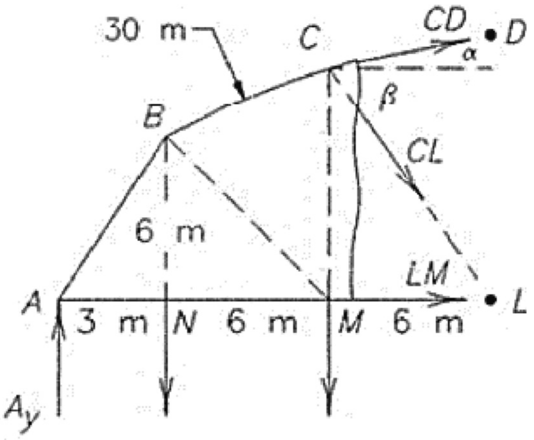


Fig. 22. Sections at the members of CD, CL, and ML.

$$F_{AJ} = F_{GH} = 0 \tag{38}$$

$$F_{CJ} = F_{EH} = L(Compression) \tag{39}$$

$$F_{DI} = 0 \tag{40}$$

Joint B.

Using equilibrium equations in x- and y-directions, have,

$$F_{BC} = F_{CD} = F_{DE} = F_{EF} = 2.67L(Compression) \tag{41}$$

$$F_{BJ} = F_{FH} = 3.33L(Tension) \tag{42}$$

Joint J

$$F_{IJ} = F_{HI} = 4L(Tension) \tag{43}$$

$$F_{DJ} = F_{DH} = -1.66L(Compression) \tag{44}$$

Finally yields,

Vertical: $F_{AB} = 5L = 525kN \rightarrow L = 105kN$ (45).

Horizontal: $F_{BC} = 2.67L = 300kN \rightarrow L = 112.36kN$ (46).

Diagonal: $F_{DJ} = 1.667L = 180kN \rightarrow L = 107.97kN$ (47).

So, with considering the safety,

$$L_{max} = 105kN \tag{48}$$

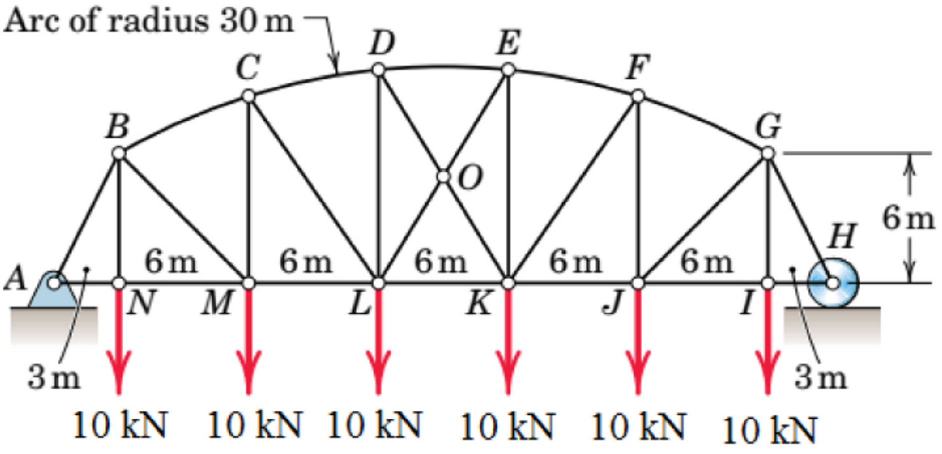


Fig. 21. Schematic view of a composite truss [27] (with minor changes).

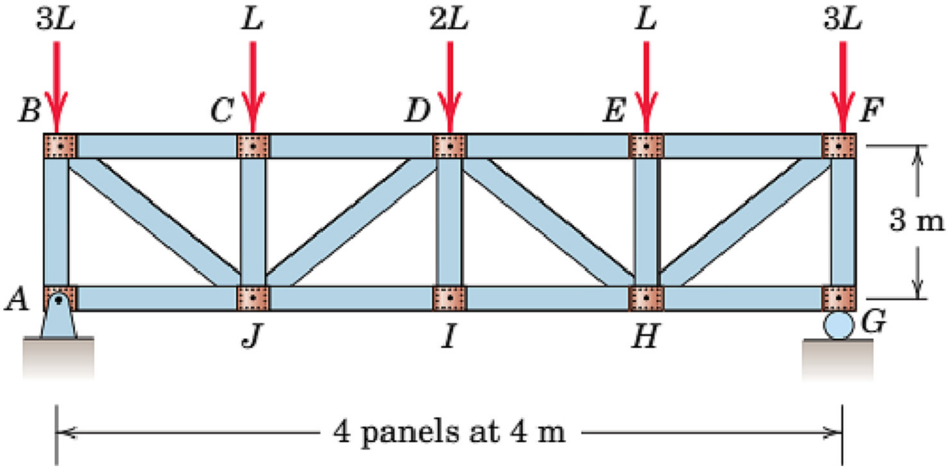


Fig. 23. A bridge with composite truss and members [27].

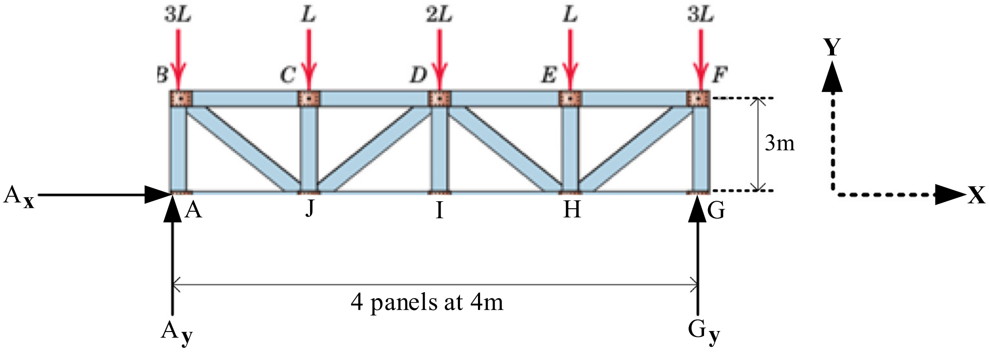


Fig. 24. Free diagram.

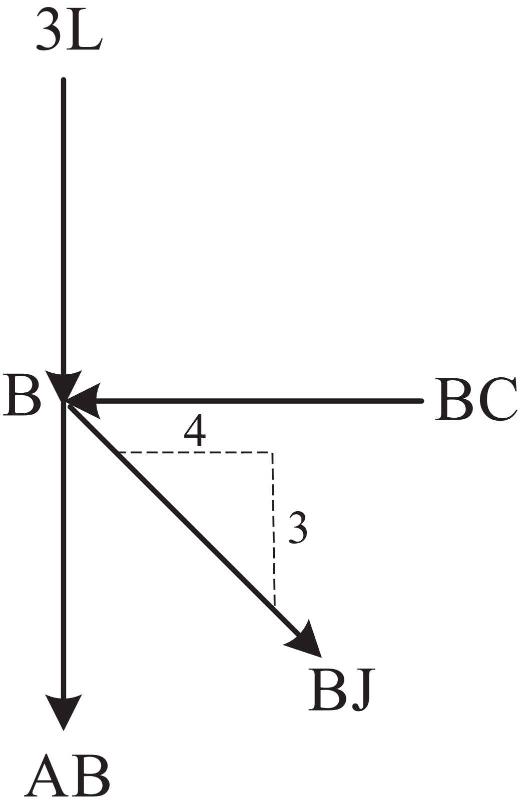


Fig. 25. Joint B.

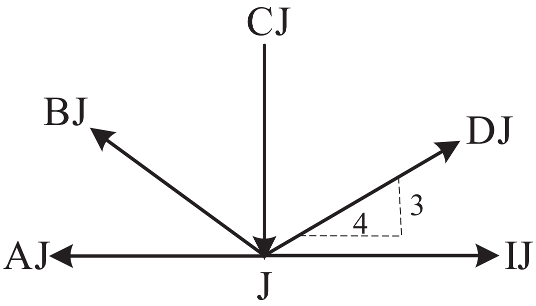
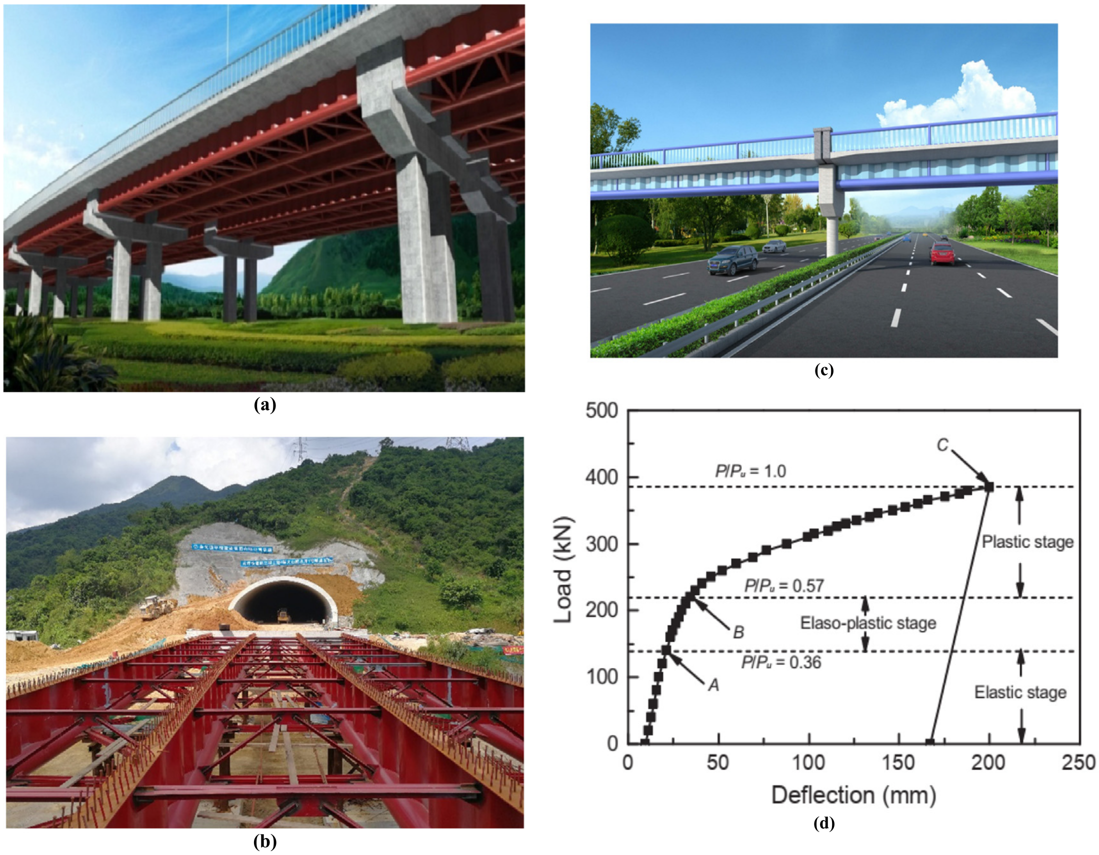


Fig. 26. Joint J.

7. Conclusion

In this study, a brief review was done on the usage of the composite components in civil engineering fields and presenting the significant results based on recent research studies. This work is about the short and selected reviews of many applied articles as well as simulation of the real and complex problems with simple geometrical problems (solved problems). This mini-effective study found the following results below,

- The significant disadvantages of carbon fiber are comprising high cost (highly expensive), irreparable carbon damage, unlike the steel fiber in the composites, and environmental damage. Design and manufacturing of carbon-fiber-reinforced polymer CFRP should consider economics and the environment (recycling and refurbishment operations).



(a)

(b)

(c)

(d)

Fig. 27. **(a)**- Maluanshan Park Viaduct: architectural rendering **(b)**- Maluanshan Park Viaduct: construction site **(c)**- A footbridge at Hebei Province, China. **(d)**- Loading/ Deflection diagram measured at mid-span of the test beam [34].

- There is a significant load resisting capacity beyond the working load demonstrated by the laminated composites' high load factors. Also, it is found that lower storey beams are more critical in column loss scenarios than upper storey beams based on linear static analysis. Further, linear static evaluation shows that beams with DCRs (Demand Capacity Ratios) greater than two will fail under sudden column loss.
- Because of the loss of total stiffness, the natural frequencies of the sandwich cylindrical panels with defects will be reduced by varying degrees. Accordingly, tailored hierarchical sandwiches have a greater bending performance than their conventional counterparts.
- When subjected to the enduring and changeable applied loads and stresses specified in the structural engineering design guidelines, "Maluanshan Park Viaduct" will reasonably work within the elastic limitation.
- The CFS truss composite floor with the PSSC slab may have a better shear capacity by using U-shaped shear connectors to delay the rupture between the profiled steel sheet and concrete slab. By using U-shaped shear connectors, composite flooring can achieve much better in-plane stiffness.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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