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Original Research Article

The experimental and the theoretical analysis of the serviceability behavior of a deployable footbridge

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ABSTRACT

This study presents a new concept of a deployable footbridge. The structural solution of the proposed footbridge comprises two parallel deployable beams as main girders and wooden boards which constitute the deck. The two beams were composed by several softwood blocks bonded to a unidirectional carbon fiber sheets layers by using an epoxy resin. In the first part of this study; we present the principle of the developed deployable footbridge. Thereafter, small-scale section prototype of the footbridge was tested under a vertical static nondestructive load on the Serviceability Limit State. The purpose of the tests is mainly to evaluate the vertical displacement responses under the static load, in every location of the prototype deck. The second purpose of these tests is to verify the deployment of the footbridge. Finally, a theoretical model based on the classical beam theory and on the theoretical structural behavior of the deployable beams was developed. The model presents the theoretical relationship between the load and the vertical displacement, under static loads, in every point of the footbridge. The predicted and the experimental results show a good agreement.

1. Introduction

Deployable structures are structures which can fold, either for transportation or for storage. They are assemblies of prefabricated elements that can be stored and transported in a compact or folded configuration and then deployed rapidly into a load bearing configuration [1]. In addition, these structures must be stable and they can carry loads in the deployed configuration.

Due to their several advantages, the deployable structures are of great use for temporary applications. They can be used as lightweight temporary emergency shelters after natural disasters, or for storage of equipment and accommodation of personnel at remote construction sites [2]. They can also be the only solution in situations of limited availability of transportation space as is the case with aerospace applications.

Temporary deployable footbridges are one of the important applications of the deployable structures. They have a wide

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area of application like in rural areas, military purpose, disaster management, alternative for damaged bridge, and forestry applications. Rahul and Kumar [3] said that these footbridges are generally short span bridges and they are made using a wide array of materials like steel, wood and composite. They indicate also in their work that the temporary footbridges have the advantages to be easily and rapidly transported, installed, and removed for reuse at multiple sites. The other advantages are the low self weight, the environment friendly and the cost is comparatively very low which makes them more economically feasible than permanent structures [4–6].

During the last several years, many research projects on the deployable bridges are made. The main goal of these researches is to build lightweight deployable bridges having a high strength and high stiffness. In this context, Averseng et al. [7] have invented a new design of deployable footbridge supported by a tensegrity structure made of 4-bars modules. The proposed system still provides a distinct advantage with its capacity to be transported in a folded configuration and deployed quickly and easily.

Ario et al. [8] have created an optimum deployable bridge based on an origami folding structure which is considered the first bridge type with a scissors structure. It is one of the rescue tools for the recovery of a bridge after a disaster.

Teixeira et al. [9] and Pfeil et al. [10] study the structural performances of new deployable bridge composed of a GFRP grid floor deck supported by prestressed truss girders. The girders were mounted by assembling GFRP tubular profiles and steel joints with bearing type connections.

Bel Hadj Ali et al. [11] and Rhode-Barbarigos et al. [12] propose a new design for a tensegrity-based footbridge. The topology of the footbridge includes bar-to-bar connections, allowing for a lightweight solution are also used the tensegrity concept to design a rapidly foldable footbridge.

Finally, Zhang et al. [13] have studied a new design of a deployable bridge composed of an aluminum deck supported by FRP trussed members. The experimental results indicated that the proposed bridge has high mechanical properties.

The aim of this work is to develop novel concept for deployable footbridge. This new footbridge is composed by a lower wooden deck supported by two foldable beams which are considered the main girders of the footbridge. The two girders were performed using several softwood blocks bonded to many unidirectional carbon fiber sheets layer's [14]. The experimental study consists to evaluate the mechanical performances of the footbridge. For it, a small-scale footbridge prototype was designed and built in the laboratory in a simply supported span of 2.70 m. This prototype was experimented in order to examine its mechanical serviceability behavior by subjecting it to a vertical nondestructive concentrated load. Thereafter, a theoretical model, based on the classical beam's theory and on the theoretical structural behavior of the deployable beams, was developed. The model presents the theoretical load–vertical displacement relationship under static loads in every point of the footbridge. This developed model was validated by the test data of the footbridge prototype.

2. Design of the deployable footbridge

The most manufactured temporary footbridges have a fixed span and capacity and they do not have the opportunity to be expanded to span a river rapidly without piers and stored in minimum space. To overcome these constraints, we propose a new design of deployable composite footbridge used for temporarily transporting displaced people. The purpose of this work is to develop a quickly installed footbridge with a broad range of load and span options.

The design process of the new footbridge is done in four different phases. The first phase is the conceptual design which is necessary to give the footbridge its geometric form and to select its appropriate structure. The second phase consists to determine the mechanical behavior of the footbridge by testing a small-section prototype. Afterwards, the theoretical structural analysis phase follows which is the most important part of the development of the new footbridge. Finally, the developed model will be validating by the comparison of the predicted and the experimental results.

The structural solution of the new developed straight footbridge comprises two parallel deployable beams as main girders. This type of beams is invented by our research group. They were studied theoretically and experimentally in our research [14]. The deck of this footbridge was manufactured by softwood boards due to their relatively low as compared to steel plates and to their high bending stresses. Afterward, each wooden board was connected in transverse direction to one block of each deployable beam by steel nails.

The deployable beam combines several softwood blocks connected to a unidirectional carbon fiber sheets by using an epoxy resin providing the full adherence [14]. In order to obtain a line straight beam, the blocks were overlapped the one another by the tenon and mortise connection. The folding and unfolding movement of the footbridge is ensured by the flexibility of the non-impregnated portion of the fibers at joints between the blocks. At these joints, the fibers were impregnated in flexible resin in order to improve the cyclic folding-unfolding strength and to ovoid their failure.

The structural solution, the geometric shape, and the folded configuration of the footbridge are illustrated in Fig. 1.

3. Experimental study

3.1. Test program

The first step of the experimental work consists to prepare a small-scale section prototype of the new deployable footbridge. Thereafter, this prototype was tested under a vertical static nondestructive load in order to evaluate the mechanical serviceability behavior and the bending response of the new footbridge, as well as the deformation recovery after unloading. The prototype was also used to verify the deployment possibility of the proposed design concepts. The materials used to prepare the prototype were also tested in order to identify their mechanical characteristics.