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New mechanism for continuous and bidirectional displacement of heavy structures: Design and analysis

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ABSTRACT

The aim of this paper is to design and study a new mechanism for moving heavy structures using the force of friction. The mechanism designed is called DCACLM and was patented in 2011. This new device is based on an inverted crawler which is able to displace heavy structures such as large span bridges in a continuous and bidirectional way. Furthermore, the DCACLM design has taken into account other important aspects such as safety and sustainability in order to develop new construction methods. Nonlinear numerical models using the Finite Element Method have been developed to study the complex structural behavior of this new mechanism. The main conclusions provide acceptable results in terms of stresses and strains for the main elements of DCACLM.

1. Introduction

Erection is a common operation in many bridge constructions but it is also one of the most dangerous phases. Most accidents take place during this stage as is indicated in previous studies by Wardhana and Hadipriono [1]. The main reasons for these collapses, without considering natural catastrophes, are human error in the design of the bridge or during its construction. It has been proved that if the bridge structure is able to resist its erection stage, it will work well during its service life as was explained by Sexsmith [2]. Sexsmith [2] studied the importance of reliability and safety in the temporary procedures, such as the erection phase. In this sense, two main aspects have to be taken into account to ensure safety during the erection procedure. The first is the time of exposure to environmental loads or operational effects. The second one is the cost increase due to the temporary equipment used in the construction.

In order to automate the main operations on large constructions, such as launching bridges, different procedures have been developed. Hydraulic jacks are commonly used to lift or erect heavy structures. New devices have been designed for specific constructions, such as the Shanghai Grand Theater, which was built in 1994, as is explained by Ke Li et al. [3]. Other systems have been used to move heavy structures: the use of synchronized jacks in Denmark by RT&S [4]; the introduction of transducers and software for real-time control in 1992, as it is explained by Bressange et al. [5]; the Beijing West Railway Station construction where 24 hydraulic jacks were needed as it is exposed by Lu [6]. Other important contributions to improve efficiency and safety of hydraulic jack operations include the electrohydraulic system developed recently by Zhinan Mi et al. [7]. In that paper, an electrohydraulic system was designed to reduce the difficulties in using hydraulic jacks to carry out the consecutive displacement of lifting and lowering. This system avoided dead times caused by starting and stopping of the jacks, and it can be applied in many construction fields where erection, lifting or displacement of heavy structures is needed.

Although the global economic crisis has impeded new construction evolution, the construction industry is still working in one direction: the improvement of methods taking into account safety and sustainability. In this sense, construction trends include the following:

- Large span bridges which reduce the number of piles and the temporary equipment during the construction procedure.
- Development of new systems which allow consecutive movement of large structures, that is, lifting and lowering for vertical displacements or forward and backward movements for horizontal displacements.
- Safety improvement in construction procedures due to important accidents which have occurred due to human errors or other factors. Safety risks must be reduced and avoided as much as possible.
- Currently, environmental considerations and sustainability in construction methods are an important consideration in this field.

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This paper presents a new system to displace heavy structures. The main application of this system is focused on launching bridges. According to previous studies, the tendency in bridge construction is to design new mechanisms which decrease the operation time, safety risks and improve the quality of the procedure. Novel ideas in bridge erection machines were presented by Rosignoli [8], where the importance of the relationship among the launching mechanism, human decisions and structural design is remarked. In this book, the most current and important devices for bridge construction are presented taking into account different procedures. For 100–120 m spans, self-launching gantries are recommended by this expert, whiles lifting frames can reach longer spans as well as curved bridges. Heavy overhead gantries are used for span-by-span erection of 80–100 m spans, but in this case, temporary pier supports are needed in every span. The use of overhead gantries requires additional operations to place them. Hydraulic cylinders are usually used to launch these structures. They work paired and in opposition, one cylinder locks the truss while the other is repositioned. In this book, is also commented other special launch devices such as the launch cylinders which are combined with low-friction surfaces and vertical jacks allow the movement of heavy structures for different complex situations. It is shown for example, friction launchers suspended from a main girder.

In this research, a new mechanism for continuous launching displacement is explained in several sections. The design, the tridimensional models and the overall dimensions are presented before the description of the working principle. Then, numerical studies of the new design are presented. In this sense, the geometrical design of the new mechanism is completed with nonlinear numerical analysis by Finite Element Methods (FEM). This methodology has been widely used to solve non-linear problems in different fields and topic. Many other FEM-based studies have been developed in engineering [9,10]. The conclusions of this paper reveal a new device which is able to move heavy structures in a bidirectional and continuous way. Although the new system can be used for other applications, this study is focused on launching bridges, mainly by means of the Incremental Launching Method (ILM). In this sense, the mechanism designed makes an important contribution to this construction methodology improving efficiency of the ILM, decreasing safety risks of the current operations and taking into account sustainability in civil engineering.

Taking into account the main application of the new mechanism designed in this paper, the review of similar systems focuses on systems for launching bridges. The main devices currently used in the ILM have been reviewed.

The most common systems used for launching bridges are launching jacks and tow systems using bars or cables just as Rosignoli explains in their books [8–11]. Both of these systems work with hydraulic jacks which provide important advantages for displacement of heavy structures. However, this kind of equipment has some important disadvantages that the construction industry wants to solve as is commented by Jiménez [12]. The main problems presented by the current systems for bridge launching are the following:

- The systems need auxiliary equipment to control the load on the bridge structure during the launching procedure in order to avoid its collapse. It is well known that the maximum loads on the bridge structure occur during the launching process as it was proved by other authors [1,13–15]. For this reason, the most serious accidents have occurred during the bridge erection when it is very important to ensure safety during launching to avoid material and human damage.
- The systems are not continuous; there are dead times due to retraction of hydraulic jacks rendering the consecutive displacement (forward and backward) of the bridge structure impossible. Currently, backward displacement is difficult: it is necessary to stop the launching, support the bridge and use many auxiliary systems to carry out this operation. In this sense, the cost and time of the construction is increased.
- Current systems cannot be used for bridge structures made of different kinds of materials or geometries.
- Due to the highest risks that are presented during the launching procedure, the efficiency of the systems should be improved in order to reduce the time of the bridge displacement. The efficiency can be increased using faster mechanisms and decreasing the dead times.
- Environmental protection during building started to be considered a few years ago. Presently, the environmental measures and the development of sustainable practices are very important for the construction industry. In this context, the existing systems are usually not reusable or recyclable for other operations. Furthermore, basic operation in civil construction did not consider environmental damage. Fortunately, social interest in environmental conservation has led to the design of new construction procedures.

2. New mechanism for displacement of structures

The authors of this research paper have been working in this topic for years. The design of new bridge construction methods and the improvement of the current disadvantages are an important research line. In this sense, two international patents have been developed to study new methods for launching heavy structures [16,17]: a new method for launching bridges based on self-supporting double decks and a new device for continuous displacement of heavy structures.

The new method for launching bridges is able to push steel bridge structures of 150 m. length reducing the auxiliary equipment due to the double height of the deck during the launching process. Two decks are moved jointly in order to increase the load capacity of the critical section during the launching procedure. In this way, the patch loading resistance is improved and the deflection of the structures is reduced. Furthermore, this new system is more efficient, safer and more sustainable than the current ones. This new methodology is an important contribution to engineering in the construction field and was patented in 2012 [16].

The new device for continuous displacement of heavy structures enables the displacement of structures of up to $7.5 \cdot 10^6$ N vertical live load. This new mechanism was patented [17], and is described in this research paper. This new device is based on an inverted crawler which is able to move heavy structures in a continuous and bidirectional way. Furthermore, the new mechanism adds safety systems to the launching procedures and it can control the load in real time during the launching procedure. The mechanism designed for continuous displacement of structures is named DCACLM (DCA Continuous Launching Mechanism).

2.1. Description of the mechanism

The mechanism presented in this paper works as an inverted crawler. Two motors move the gears which displace a couple of transmission chains. The transmission chains transmit the horizontal force which moves the bridge structure. The structure is supported by a non conventional chain called, a support chain. The support links have a plate of elastomer at the top to displace the structure by means of the force of friction. These sheets can be changed depending on the material of the structure which is moved. The links of the chains are joined by bolts which have rollers in order to follow two rails. In Fig. 1, the main elements of the DCACLM are shown.

One of the most important innovations of the DCACLM is the system for load compensation, shown in Fig. 2. This system is able to control the normal load over the mechanism during the launching process as well as to adjust the support links to the deformed shape of the structure at all times. The system for load compensation is also a safety system because it can stop the launching process if overloads are detected. The hydraulic jacks are able to support the total normal load due to the bridge structure. These hydraulic jacks detect the normal load which can be different between both of them and applied the reaction