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Development of a procedure for the structural design of roller coaster structures: The supporting structures

C. Braccesi, F. Cianetti*

University of Perugia, Department of Industrial Engineering, Via. G. Duranti 1/A-4, 06125 Perugia, Italy

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ABSTRACT

In this paper a procedure for the design of the structures of a generic roller coaster (*RC*) is described. This activity is part of a partnership that the authors are entertaining with one of the major European amusement park industries. The full procedure, developed on theoretical bases and under simplified hypotheses, aims to make designers able to properly and quickly size the complete structure (for complete structure authors mean rails and support structures). In the present paper the design of the support structures is presented. The data, needed by this procedure, are: the rail track tridimensional geometry and the time histories of contact forces between vehicles and rails. The procedure has been subsequently verified by applying it to an existing *RC* in order to test all its capabilities and foresee future development and improvement, aiming to insert it in a consolidated general procedure, ever growing and expanding.

1. Introduction

The activities of this paper fit inside a research agreement signed between the *Department of Industrial Engineering* of the *University of Perugia* (Italy) and *Antonio Zamperla* S.p.A. (Italian company dedicated to the design, construction and installation of amusement park rides and equipment) [1–4]. Within the procedure thus far developed, aimed at the design of roller coasters (*RC*), the present activity has set the goal to analyze issues of dimensioning and verification of the structures, that is rails and supporting structures (Fig. 1).

In the paper, a design procedure for supporting structures, developed on a theoretical basis, is described. Although not without simplifying assumptions, it aims to fully respond to the need of the designer to quickly but also properly size all the structures that are adequately verified by a series of numerical structural calculations (i.e. by using the finite element approach – *FEA* [5,6]). The databases of this procedure are the three-dimensional rail track geometry and the interaction forces between the rail and the vehicles. The development of the rail track geometry is conducted in a computer aided design (*CAD*) environment developed by the authors [1,2] inside a commercial *CAD* software, also with the help of simplified numerical dynamic simulation tools, made with the numerical language (*VBasic*) supported by the software itself. The interaction forces are instead obtained by a modeling and dynamic simulation multibody [7] tool, designed and built for the aforementioned activities [3].

The hypothesis on which the present work is based is that the design of the structures can be divided into two logical steps, the first on the sizing of the *rail structure* and the second on the sizing of the *supporting structure*. Taking into account the mutual interaction of the two substructures from the start of the design is quite expensive and, therefore, the choice of splitting the design of the structures into two sub-processes was necessary. Consequence of this hypothesis was, however, the additional choice of a series of successive hypotheses that, in order not to lose information, make the design process at least as safe as the standard one.

In a previous paper [4] the rails design procedure is described and validated. The present paper is focused instead on support structures design. The design of the supporting structure is certainly more difficult than the rails' one due to the many constraints on its geometric definition (i.e. *roller coaster* made within buildings) and the infinite number of possible types of construction, ranging from simple portals to spatial frames (Fig. 2).

The aim of this work was to provide the designer with the initial structural information useful for a definition of the subsequent final design solution. It is only possible to assist him in the definition of solutions that he arbitrarily defines, guided by his experience.

Deformability being the more binding parameter and considering such compliance attributable to supporting structures, the design procedure, developed by the authors, was aimed at obtaining the stiffness matrix to be associated to the connection points between rail and supporting structures, points previously chosen by the designer. This choice, in addition to being aided by the results of the design phase of

* Corresponding author.
E-mail address: filippo.cianetti@unipg.it (F. Cianetti).

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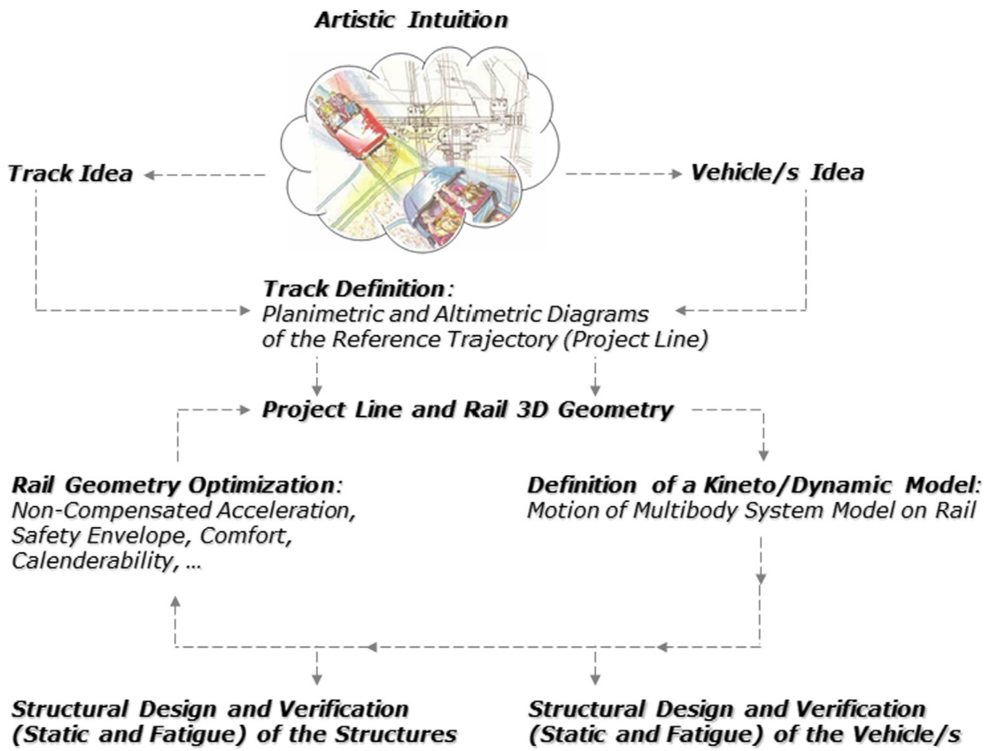

Fig. 1. Flow chart of the design process through the developed general procedure.

Fig. 2. Example of some roller coaster supporting structures typologies.

the rail (i.e. allowable span length [4]), is also supported by a further analysis of the dynamic loads, by measuring the same in the local coordinate system [1–4] and as a function of the track curvilinear abscissa, highlighting areas requiring structural support (rails/supporting structure connection). Starting from the individual time histories of reaction forces, obtained from a *FEA* static transient simulation performed on the 3D model of the designed track, constrained with perfect constraints in its local reference system and loaded by load time