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An approximate method of dynamic amplification factor for alternate load path in redundancy and progressive collapse linear static analysis for steel truss bridges

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ABSTRACT

Linear static analysis with an alternate load path using dynamic amplification factor (DAF) is often used for redundancy and progressive collapse analysis of steel truss bridges to avoid using the more time-consuming dynamic analysis. This study presents an empirical equation to calculate the DAF for this type of analysis against the initial sudden member fracture. Currently, this analysis employs an approximate model with a single degree of freedom to calculate the DAF. With a 5% damping ratio, the constant DAF of 1.854 is used for all types of steel truss bridges. However, this approach is inaccurate because the DAF varies between bridges and with the location of the fractured members as well. Considering some of the approaches developed for building structures but adapting them to steel truss bridges, this paper proposes an empirical equation that allows for the computation of the DAF from the maximum norm stress σ_{is}/σ_{iy} in static linear elastic analysis of the damaged model with a member removal. A total of 30 illustrative cases for two typical steel truss bridges are investigated to obtain the data points for the empirical equation. The proposed empirical equation is the enveloped line offset from the best fit line for the data points in illustrative cases.

1. Introduction

Progressive collapse is the spread of an initial local failure from element to element, member to member, eventually resulting in the collapse of a part, entire structures or a disproportionately large part [1]. A sudden member failure is a dynamic event in which the structural motion is initiated by energy released by the sudden loss of a load-carrying member. Four methods, including linear static analysis, nonlinear static, linear dynamic and nonlinear dynamic methodologies, are available for redundancy and progressive collapse analysis of structures for the sudden fracture of a member or component [2,3]. The event of a sudden member fracture relates to both the primary loading, which causes the initial fracture, and impact loading, which causes structural motions after the initial fracture. The dynamic method is a direct solution to address impact loading and the dissipation procedure of the energy induced by the initial member fracture. This approach is accurate, but it requires much intensive computation with time-history transient analysis. Static analysis with an alternate load path,

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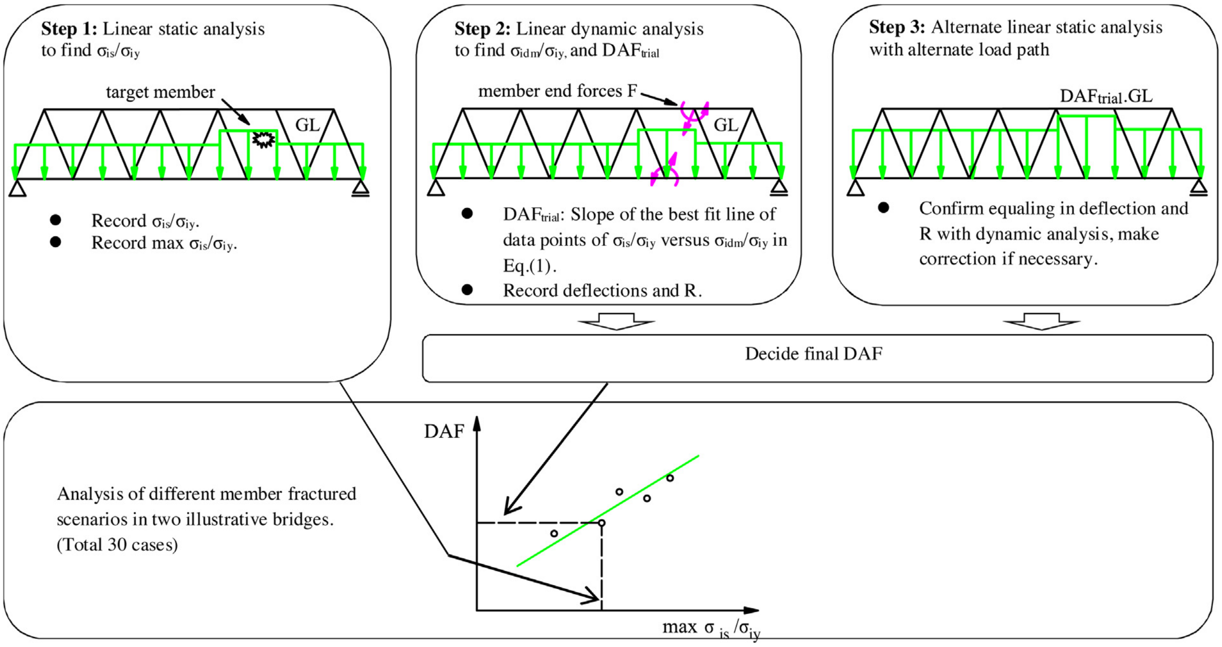

Fig. 1. Illustration of the procedure to obtain data points of DAF versus max normalized stress and how to find the empirical DAF formula.

which amplifies the primary loading with a dynamic amplification factor (DAF) to form the impact loading, is an alternative approach for analysis without using dynamic analysis.

Currently, linear redundancy and progressive collapse linear static analysis of steel truss bridges have employed a single degree of freedom (SDOF) model to conventionally calculate the DAF [4,5]. With a 5% damping ratio, the conventional DAF is 1.854, constant for all bridges. This approach is conservative because the bridge system acts as multiple degrees of freedom instead of a single degree of freedom. The DAF varies between bridges and with the location of the fractured members, as well.

To consider a model with multiple degrees of freedom, Goto et al. propose the root mean square mode combination method to approximate the DAF [6]. This approach is moderately accurate and requires some correction factors. Although no other studies have yet been published about the approximation of the DAF for bridge systems, such approaches by Liu [7], McKay et al. [8], DoD, U.S. [9], and Stevens et al. [10] that approximate DAF in a building system are valuable. McKay et al., DoD, U.S., and Stevens et al. propose different linear functions of norm rotation, which is the ratio of the total member rotation to the member-yield rotation, to compute the DAF of steel buildings. On the other hand, Liu computes the DAF by using the function of max(M_u/M_p), where the max operator is applied to all affected beams that are directly adjacent to and above the removed column. M_u and M_p are the factored moment demand under the original unamplified static gravity loads and the factored plastic moment capacity, respectively, of an affected beam. These approaches may be limited to only one building system because the norm rotation and M_u/M_p are critical parameters for the behavior of a building system. In a steel truss bridge system, when a member fractures, in addition to axial force, the members are also subject to bending moments. Considering this behavior, this study proposed the DAF as a function of the maximum norm stress σ_{is}/σ_{iy}, where σ_{is} and σ_{iy} are stress in a static analysis and the yield stress of bridge members. In this paper, a total of 30 illustrative cases are investigated in 3D models. The empirical equation to calculate the DAF was defined as the enveloped line offset from the best fit line for the data points from illustrative cases.

2. New DAF calculation method and analysis procedure

The empirical equation to calculate the DAF is defined as a function of the maximum norm stress σ_{is}/σ_{iy}, where σ_{is} and σ_{iy} are the stress in static analysis and yield stress of the i^{th} bridge member. For a given member fracture scenario, the DAF is obtained by the stress DAF and is then confirmed by an alternate static analysis with amplified loading using the calculated amplification factor to ensure that the structural responses best match those from the linear dynamic analysis. The process of computing the DAF in a given damaged scenario undertakes the following procedure, as in Fig. 1.

Step 1: Statically apply the primary load GL, as defined in Section 3.3, to the damaged bridge, remove the member that is being fractured and perform the static linear elastic analysis. Then, measure the norm stressσ_{is}/σ_{iy} of the members and the maximum σ_{is}/σ_{iy}, where σ_{is} and σ_{iy} are stresses in the static analysis and yield stress of the i^{th} bridge member.