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PROGRESSIVE COLLAPSE OF CABLE STAYED BRIDGE BY ANALYTICAL AND USING STAAD PRO

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ABSTRACT
The study of progressive collapse of cable stayed bridges by analytical method is common now a days. An attempt has been made to study design using software. Here, we have studied the works carried out by other researchers. They have studied different types of cable pattern, about different factors affecting the collapse of bridges, found out different codes that give information about failure, causes of failure etc.

Keywords:
Collapse, Cable Stayed Bridge, STAAD PRO

INTRODUCTION

Aoki [1] presented that in bridge structures, loss of critical members (e.g., cables or piers) and associated collapse may occur due to several reasons, such as wind (e.g., Tacoma narrow bridge), earthquakes (e.g., Hanshin highway) traffic loads (e.g., I35W Mississippi River Bridge) and potentially some blast loadings. One of the most infamous bridge collapses is the Tacoma Narrow Bridge in United States. This suspension bridge collapsed into the Tacoma Narrow due to excessive vibration of the deck induced by the wind. The collapse mechanism of this bridge is called "zipper-type collapse", in which the first stay snapped due excessive wind-induced distortional vibration of the deck and subsequently the entire girder peeled off from the stays and suspension cables. The zipper-type collapse initiated by rupture of cable(s) also may occur in cable-stayed bridges and accordingly guideline, such as PTI, recommends considering the probable cable loss scenarios during design phase. Moreover, the possible extreme scenario which can trigger the progressive collapse of a cable-stayed bridge should be studied. Thus, there are three main objectives for this research, which are the effect of sudden loss of critical cable(s), cable loss due to blast loadings and progressive collapse triggered by the earthquake. A finite element (FE) model for a cable-stayed bridge designed according to Australian standards is developed and analyzed statically and dynamically for this research purpose. It is noted that an existing bridge drawing in Australia cannot be used due to a confidential reason. The bridge model has steel deck which is supported by total of 120 stays. Total length of this bridge is 1070m with 600m mid-span.
This thesis contains 8 chapters starting with the introduction as chapter 1. In chapter 2, comprehensive literature review is presented regarding three main objectives. In chapter 3 to 5, results of the cable loss analyses are presented. In chapter 3, the dynamic amplification factor (DAF) for sudden loss of cable and demand-to-capacity ratio (DCR), which indicate the potential progressive collapse, in different structural components including cables, towers and the deck are calculated corresponding with the most critical cable. The 2D linear-elastic FE model with/without geometrical nonlinearity is used for this analysis. It is shown that DCR usually remains below one (no material nonlinearity occurs) in the scenarios studied for the bridge under investigation, however, DAF can take values larger than 2 which is higher than the values recommended in several standards. Moreover, effects of location, duration and number of cable(s) loss as well as effect of damping level on the progressive collapse resistance of the bridge are studied and importance of each factor on the potential progressive collapse response of the bridges investigated.
As it was shown in chapter 3, a 2D linear-elastic model is used commonly to determine the loss of cable. However, there is a need to study the accuracy and reliability of commonly-used linear elastic models compared with detailed nonlinear finite element (FE) models, since cable loss scenarios are associated with material as well as geometrical nonlinearities which may trigger progressive collapse of the entire bridge. In chapter 4, 2D

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and 3D finite element models of a cable-stayed bridge with and without considering material and geometrical nonlinearities are developed and analyzed. The progressive collapse response of the bridge subjected to two different cable loss scenarios at global and local levels are investigated. It is shown that the linear elastic 2D FE models can adequately predict the dynamic response (i.e., deflections and main stresses within the deck, tower and cables) of the bridge subject to cable loss. Material nonlinearities, which occurred at different locations, were found to be localized and did not trigger progressive collapse of the entire bridge.

In chapter 5, using a detailed 3D model developed in the previous chapter, a parametric study is undertaken and effect of cable loss scenarios (symmetric and un-symmetric) and two different deck configurations, i.e., steel box girder and open orthotropic deck on the progressive collapse response of the bridge at global and local level is investigated. With regard to the results of FE analysis, it is concluded that deck configuration can affect the potential progressive collapse response of cable-stayed bridges and the stress levels in orthotropic open decks are higher than box girders. Material nonlinearities occurred at different locations were found to be localized and therefore cannot trigger progressive collapse of the entire bridge. Furthermore, effect of geometrical nonlinearities within cables (partly reflected in Ernst's modulus) is demonstrated to have some effect on the progressive collapse response of the cable-stayed bridges and accordingly should be considered. In chapter 6, the blast loads are applied on the bridge model and determined the bridge responses, since the blast load is one of the most concerned situations after 911 terrorist attacks. The effect of blast loadings with different amount of explosive materials and locations along the deck is investigated to determine the local deck damage corresponding to the number of cable loss. Moreover, the results obtained from the cable loss due to blast loadings are compared with simple cable loss scenarios (which are shown in chapter 3 to 5).

In addition, the potential of the progressive collapse response of the bridge at global and local level is investigated. With regard to the results of FE analysis, it is concluded that the maximum 3 cables would be lost by the large amount of TNT equivalent material due to damage of the anchorage zone. Simple cable loss analysis can capture the results of loss of cable due to blast loadings including with local damages adequately. Short cables near the tower are affected by blast loadings, while they are not sensitive for the loss of cables. Furthermore, loss of three cables with damaged area did not lead progressive collapses. Finally, in chapter 7, dynamic behavior of cable-stayed bridges subjected to seismic loadings is researched using 3D finite element models, because large earthquakes can lead to significant damages or even fully collapse of the bridge structures. Effects of the type (far- or near-field) and directions of seismic loadings are studied in several scenarios on the potential progressive collapse response of the bridge at global and local level. According to the case studies in this chapter, it is shown that near filed earthquakes applied along the bridge affected to deck and cables significantly. Moreover, the mechanism of bridge collapsed due to longitudinal excitation is analyzed by an explicit analysis, which showed the high plastic strain occurring around the pin support created the permanent damage. The summary and suggestions for this research are shown in final chapter 8.

A study on progressive collapse response of cable-stayed bridges for deflection and axial force in cables carried out by Wani and Talikoti [2] stays of cable stayed bridges have potential to loss their support initially by extreme loadings such as earthquake, thunder strike, vehicle impact and wind. The sudden loss of cable(s) provides unpredictable stress redistribution on the deck towers, as well as the large deflection of the entire bridge. Considering such a sudden loss of cable in the design of a cable-stayed bridge is essential. Although cable loss scenarios are associated with material as well as geometrical nonlinearities, in design of cable-stayed bridges, such an extreme loading scenario is analyzed typically by using linear elastic models. In this paper, a linear elastic 2D and a fully nonlinear 3D finite element model of an idealized steel cable stayed bridge are developed and analyzed to determine the effect of sudden loss of cable on the progressive collapse of the bridge at global and local stress levels. A parametric dynamic analysis for the bridge model with different cable loss scenarios under symmetrical loading condition is investigated. The deflection which is equal in both the spans of the bridge with healthy bridge condition changes into major deflection in one span after loss of cable in another span. Also, the axial force in cables unevenly distributed with loss of any cable which enhance risk of collapse with moving loads. The objective of study was to study the behavior of cable stayed bridges for sudden loading such as blast loading, earthquake etc. with progressive collapse. To study its behavior for maximum deflection and increase in axial force in other cables and collapse.

They adopted the methodology as a thorough literature review to understand the basic concept of the topic like seismic evaluation of bridge structures, dynamic amplification factor, progressive collapse and nonlinear analysis by referring books, technical papers or research papers, Data collection, Progressive collapse with successive cable loss, Modeling the cable stayed bridge model 200meters length, 6 meters wide with two spans

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and one pylon 60 m high at center using SAP2000 v.17, Carry out analysis with bridge construction scheduler which automatically takes all the loadings with construction stages. Cross verified with another model giving dead and moving loads. And check in results for deflection and axial forces in cables. This is healthy bridge model (M1), Preparing another model with loss of one or more cable(s) having maximum axial force before and analyzed, and again check for deflection and axial forces in results. (M2), Both the models M1 and M2 compared and prepared conclusions.

2D view of the M1 model They have given the conclusion as the tensile stresses in cables, following symmetrical or unsymmetrical cable loss and loading scenarios remained well below the breakage stress of the cables, and accordingly, for the cable stayed bridge considered in this study, loss of one or even two cables did not trigger a zipper type progressive collapse. In the analyzed bridge, material nonlinearity (yielding of steel) and buckling of steel plates did not occur at global as well as local levels. Accordingly, it was concluded that the zipper-type collapse triggered by formation of plastic hinges is unlikely to happen in the cable stayed bridges that have lost two cables or less.

Das et. al. [3] made the research on progressive collapse of a cable stayed bridge.

Progressive collapse, a structural failure, is triggered by a localized structural injury and eventually develops a chain reaction resulting in breakdown of a major portion of the structural system. It is a dynamic event initiated by a release of internal energy due to the instantaneous loss of a structural affiliate disturbing the initial load equilibrium and thus, the structure vibrates until either a new equilibrium position is found or it collapses. Recent events, such as the collapse of Haeng-Ju Grand Bridge in Seoul in 1992 during its construction highlighted the need to incorporate progressive collapse into the design of major bridges. Bridges are primarily horizontally aligned structures with one main axis of extension. Hence, the possible mechanisms of collapse are different as compared to buildings. In case of Cable-stayed bridges, the loss of cables should be measured as a possible local failure since the cross sections of cables are usually small, and therefore provide low resistances against accidental lateral loads stemming from vehicle impact or accidental actions. The loss of cables can lead to overloading and rupture of adjacent cables. In addition, the stiffening girder shows compressive behavior and a cable loss reduces its bracing against buckling.

They have used the model as 2D geometrical configuration of the model analyzed. The total span length of the cable stayed bridge is 822.96 meter supported by four pylons of height of 122.3 meter, each pair resting upon two 13 meters high piers. Two portals are present between each pair of pylons. The deck is hinged with the leftmost pier and roller supported on the rightmost one.

They have explained the realistic structural response to accidental or arbitrary loading is always nonlinear. Thus, material and geometrical nonlinearity should be considered to obtain the actual behavior of the cable stayed bridges under different cable loss cases. Plastic hinges have been used in SAP 2000 program to consider material nonlinearity for different elements. For each cable loss case there would be two prominent failures to observe, overloading of adjacent cables due to local redistribution and (ii) flexural failure of the steel girders. Therefore, the material nonlinearity has been considered for the cables, girders and the deck. As the cables can only be in tension, a compression limit of zero has been assigned to them and an axial plastic hinge is introduced in the middle of each cable element. The yield stress was obtained from the material properties of a cable as 0.6 GPa. The strain at onset of strain hardening is taken to be 2%; then the strain at rupture is taken to be 5%. The girders are subjected to both axial forces and bending moment. Thus P-M2-M3 hinges have been introduced into these elements. Hinge properties based on ASCE-365 guidelines are adopted. Instead of plastic hinges, nonlinearity is defined in its sectional properties window. Due to large deflections after the loss of different cables, the effect of geometrical nonlinearity is considered in the nonlinear static and dynamic analysis. All materials used have been isotropic and homogeneous in nature.

They concluded as A conceptual understanding of the collapse progression throughout the whole structure is also derived from the results. Due to the sudden loss of the mentioned cables for each case, upright deformations start to develop in the longitudinal girder of the damaged cable plane. The anchorage joints of the initially ruptured cable(s) on the pylon and deck are pushed in the opposite direction due to the unloading impact force and thus generate an extra axial force in the nearby cables. Normal forces acting on this bridge girder gets transferred to the longitudinal girder of the undamaged cable plane. These girders can’t resist the additional normal forces and commence to buckle in the vertical direction. So, vertical deformations grow strongly and can’t be stopped since the bridge deck is not restrained by fix supports in the longitudinal direction and thus, ultimate stresses exceed in the bridge girder. The inertia effect of the pylon and deck and the downward deflection of the longitudinal girder of the intact cable plane finally caused the rupture of the nearby cable. This

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continues in the vicinity till the structure tries to regain its symmetric configuration and hence, an end cable fails in the other half of the bridge. The whole phenomenon discussed is repeated and the girders in the middle of the decks fail due to flexure. Forces get transferred to the pylons and they are pulled towards the center of the deck, causing final break down of the whole bridge structure.

Progressive Collapse of Bridges—Aspects of Analysis and Design given by Starossek [4] as progressive collapse is characterized by a distinct disproportion between the triggering event and the resulting widespread collapse. If we take this disproportion as the defining feature of progressive collapse, then the cause of initial failure, be it a local action or a local lack of resistance, is irrelevant to this definition. Progressive collapse has played a role in such catastrophic events as the collapse of the Alfred P. Murrah Federal Building (Oklahoma City, 1995) and the World Trade Center towers (New York, 2001), but in a large number of less dramatic failures as well which also include some bridge collapses. Following the Ronan Point failure in 1968, progressive collapse has received more widespread attention. Likewise, since the events of September 11th, 2001, research on progressive collapse has intensified. The term robustness is defined here as insensitivity to local failure. Different structural systems exhibit different degrees of robustness. Such differences are neglected even in modern design procedures using partial safety factors. Other problems of current design approaches are that low probability events are neglected and that admissible failure probabilities cannot be specified for risks of the type "low probability / high consequence." Additional considerations are therefore necessary to ensure structural safety after the occurrence of accidental circumstances. Such additional considerations have in the past been made only in particular cases, e.g., for embassy buildings or very long bridges, i.e., for obviously exposed or vulnerable structures, and mostly at the engineer's discretion. The following begins with a presentation of failure events and an overview of previous research in progressive collapse and of the current state of codification to deal with this problem. To prepare the further discussion, the two terms robustness and collapse resistance are defined. Based on a detailed analysis of the deficiencies in current design methods, a pragmatic design approach is suggested and a set of corresponding design criteria is presented. These include possible design methods such as the alternate-load-paths approach and the hitherto little-noticed compartmentalization approach. It is referred to various examples which include a large multi-span girder bridge. The various design methods are compared in regard to their adequacy for different types of structures. Finally, the application of these general concepts to various types of bridges is discussed in more detail.

He has used the standard as the requirement for structural resistance to progressive collapse is not yet consistently embodied in the structural design standards. Dusenberry and Juneja (2003) subject the building codes of the U.S. and Canada to a critical assessment. Even when progressive collapse is mentioned in those documents (in particular, in NRC (1996), ASCE (2002), ACI (2002)), it is done so without giving much practical guidance and, if so, without general applicability. The ASCE guideline 7-02 (ASCE 2002) states: "… buildings and structural systems shall possess general structural integrity, which is the quality of being able to sustain local damage with the structure as a whole remaining stable and not being damaged to an extent disproportionate to the original local damage …" More specific design rules, where given, are of prescriptive nature and limited to specifications for detailing the concrete reinforcement and connections. Design objectives and rules for analysis and checking are not further specified. The implementation of these codes in individual cases is left to the engineer's discretion and ability.

The arguably most detailed design rules, even if limited to buildings, can be found in the guidelines for U.S. federal office buildings (GSA 2003). Requirements are defined, design methods based on analysis but using simplified calculation methods are described, and prescriptive design rules are given.

The CEB-FIP Model Code 1990 (CEB 1991), requires that structures should withstand accidental circumstances without damage disproportionate to the original events—which is a more general requirement than that of ASCE (2002). Eurocode 0 (EC 0 2002), by stressing that the failure of one element shall not lead to the failure of the entire structure, is in line with ASCE (2002). A more sophisticated approach containing detailed design rules, even if limited to buildings, has been drafted for the future Eurocode 1, Part 1-7 "General Actions – Accidental Actions" (EC 1-1-7 2004).

At present, precise design and analysis rules only exist for special types of structures. For the design of cable-stayed bridges, for instance, the PTI Recommendations (PTI 2001) require that the sudden rupture of one cable shall not lead to structural instability and specify a corresponding load case "loss of cable." Beside this, requirements concerning progressive collapse are mainly found in building standards. In this regard, the British standards have a long tradition starting with the Ronan Point collapse. Detailed prescriptive design rules for steel buildings can be found in BS5950-1 (2001). Moore (2003) gives a survey of the historical and current

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development of British building standards. The most recent British provisions are given in The Building Regulations 2000 (2004); they are similar in scope and content to the draft of Eurocode 1 (EC 1-1-7 2004).

He suggested the design approach which follows from the discussion above that the shortcomings of current design methods can at best only partly be overcome within the framework of reliability theory. The possibilities of improvement which do exist are not yet explored today and might prove insufficient in the future. Still, guidance is needed on how to design a collapse-resistant structure that is insensitive to accidental circumstances. It is therefore suggested to use, for the time being, the following pragmatic approach.
On the one hand, the design methods as described in the current codes are applied. They are based on reliability theory and reflected in the codes by partial safety factors and load combination schemes. In view of the inconsistencies outlined above one could argue that the number of load combinations prescribed by some codes can be reduced because it is exaggerated when compared to the actually achieved accuracy. On the other hand, an additional assessment with particular regard to collapse resistance is made. This procedure is further described in the subsequent sections in which thoughts on an appropriate additional design process are put forward along with possible avenues of investigation and enhancement of collapse resistance. This additional investigation is not necessarily based on reliability theory but rather on judgment and a decision-making process. Analyses are carried out deterministically.
He concluded that his approach is contrary to the recommendation made in EC 1-1-7 (2004) to perform nothing but a risk assessment for structures of the highest consequence class. It follows from the preceding discussion, however, that such a study can at best supplement, not replace, a design approach as it is presented in this paper. The structural designer, not the reliability theorist, should be in charge of the collapse-resistant design of a real structure. On the other hand, reliability theory can play a role in a more detailed comparison of the design methods discussed here and in determining some design criteria like exposure, assumable extent of accidental circumstances, or applicable safety factors. Nevertheless, these and other design criteria might in the end be left to engineering judgment. The dependency of the accuracy of such judgment, and the importance of reliability theory, is relatively high when using the design strategy "high safety against local failure," less so for the design method "alternate load paths," and minimum for the design method "isolation by compartmentalization." Still other design criteria need to be stipulated in a decision-making process. The choices to be made in that process, e.g., concerning the acceptable extent of collapse progression, are relatively transparent so that an informed societal consensus should be possible.
The alternate-load-paths approach and, in particular, the prescriptive design rules based on that idea should be applied with discretion. Forces should be determined based on the overstrength of elements introduced for continuity and the force transfer should be checked down to the foundation. Compartmentalization can be accomplished either by a strengthening or by a reduction of continuity at the compartment borders. In other words, the compartment borders must be able to sustain either large forces or large displacements. For certain structures, compartmentalization is the more suitable approach to prevent progressive collapse a fact that has gone nearly unnoticed in the structural engineering community. If this option has been overlooked, one reason might be that the terms continuity, redundancy, and robustness are intuitively equated, a tacit assumption which is justified at best for particular types of structures.
Rathod and Jivani [5] progressive collapse analysis of cable stayed bridge considering different cable geometry given that bridges are the lifeline and important structure for any nation. Cable-stayed bridges are one of the most popular long-span bridge type due to its structural efficiency and pleasing aesthetics. Stays of cable-stayed bridges are critical structural elements which are subjected to corrosion, abrasion, wind, vehicle impact and malicious actions and these extreme loading scenarios may lead to severe damage and loss of cable which demands the progressive collapse analysis. Progressive collapse is a continuous spread and enlargement of initial local failure of structures, which is characterized by a disproportion between the initial failure and its resulting widespread collapse. Several bridge accidents occurred in recent years have demonstrated that the consequences of progressive collapse may be unpredictable and serious. It has been found that the ability to resist the collapse is determined not only by structural load-bearing capacity, but also by other structural attributes. Although great efforts have been contributed to the progressive collapse of building structures, comparably small attention have been paid in the same problem about bridge structures. In this research Xing jia bridge is consider with different geometry fan type, harp type & semi harp type cable system. Analysis of cable stayed bridge is done using computer program SAP. Results obtained in form of Time period, Displacement and axial force are compared for different cable patterns. The results of the comprehensive

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evaluation of the cable failure show that the tread of the progressive failure of the cable-stayed bridges decreases when the location of the failed cables is closer to the pylon.

They found the necessity as a lot of collapses and performance failures have happens since the cable bridge inventions. Stays of cable-stayed bridges are critical structural elements which are subjected to corrosion, abrasion, wind, vehicle impact and malicious actions and these extreme loading scenarios may lead to severe damage and loss of cable.
Such cable loss scenarios would lead to high impulsive dynamic loads in the structure that can potentially trigger a "zipper-type" progressive collapse of the entire bridge. Analysis of sudden loss of cables in cable stayed bridge is extremely critical and it has drawn the attention of researchers in recent years.
They modelled the bridge as in this paper comparison of cable stayed bridge for different cable patterns for same span under dead load & live load in the form of vehicle load is carried out for static analysis. The analysis is carried out using widely used in SAP 2000. For study purpose The Xing Jia bridge considered which is 3-span composite cable-stayed bridge with an overall length of 420m (100m+ 220m+ 100m). The deck is 15.6 m wide. It comprises two longitudinal steel girders, approximately 2.5 m deep, transverse steel trusses at 3 m spacing and a reinforced concrete slab between 300 mm in depth. The deck of each cable-stayed cantilever section is supported by a total of 10 cables, with 10 cables arranged in each semi-fan configuration on each side of the pylon, in two planes, either side of the bridge deck. Each reinforced concrete pylon comprises two towers and two crossbeams, the lower one supporting the deck.

CONCLUSION

1. Reviewed and studied papers on progressive collapse of cable stayed bridge.
2. Studied different types of cable pattern.
3. Got to know about different factors affecting the collapse of bridges.
4. Studied and found out different codes that give information about failure, causes of failure etc.

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