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(Research Article)

# Progressive Collapse Analysis of Curved Cable Stayed Bridge

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***Abstract***

*This study examines the progressive collapse behavior of curved cable-stayed bridges, evaluating deck curvature (75–175m), pylon types (H-shape, single), and cable systems (fan, harp) using 24 MIDAS Civil finite-element models. Analyses under IRC Class 70R loads reveal deck curvature intensifies torsional demands, with H-pylons experiencing 30–35% higher torsion in harp systems versus fan systems. Single pylons exhibited minimal cable-geometry sensitivity but increased longitudinal moments (Y-direction) under tighter curvatures. H-pylons demonstrated reduced longitudinal moments but higher Z-displacements in fan systems, while harp systems showed controlled displacements. Time period analysis indicated fan systems' lower stiffness, with periods 10–15% longer than harp systems. Cable failure simulations highlighted inner cables near pylons redistributing 25–40% less force than outer cables, improving collapse resistance. Curved decks induced force imbalances, with curvature-side cables sustaining up to 18% higher pretension. The study advocates harp configurations with H-pylons for curved spans due to balanced load distribution and redundancy, while emphasizing the necessity for curvature-specific IRC guidelines. These findings offer critical insights for optimizing resilience against progressive collapse in geometrically complex cable-stayed bridges, informing design strategies to enhance structural robustness.*

*Keywords: Progressive collapse, Cable-stayed bridges, Deck curvature, MIDAS Civil, Torsional response*

## 1. Introduction

Cable-stayed bridges have emerged as a cornerstone of modern infrastructure, celebrated for their structural efficiency, aesthetic versatility, and adaptability to long-span applications. Over recent decades, their design complexity has evolved to accommodate challenging site-specific demands, including horizontally curved alignments necessitated by urban spatial constraints, environmental considerations, or intricate transportation networks. While straight cable-stayed bridges are well-documented in engineering literature, curved configurations introduce unique challenges, such as amplified torsional stresses, asymmetric load distributions, and dynamic coupling effects, which remain underexplored in current design standards. The vulnerability of cable-stayed systems to progressive collapse—triggered by sudden cable loss due to extreme loads, corrosion, or accidental damage—further underscores the need for curvature-specific resilience strategies.

Existing guidelines, such as the Indian Road Congress (IRC) codes, lack explicit provisions for curved cable-stayed bridges, relying instead on generalized torsion concepts. This gap is critical, as curved decks inherently redistribute forces unevenly, exacerbating the risk of cascading failures.

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Previous studies have focused predominantly on straight spans or isolated parameters like pylon geometry, leaving a paucity of holistic research on the interplay between deck curvature, cable patterns, and pylon configurations. For instance, while fan and harp cable systems are well-understood in linear geometries, their performance in curved decks—where centrifugal forces and geometric nonlinearities dominate—remains ambiguous. Similarly, the role of H shape versus single pylons in mitigating torsional instability under progressive collapse scenarios warrants deeper investigation.

This study addresses these gaps by systematically analyzing the structural behavior of curved cable-stayed bridges under varying geometric and loading conditions.[9] Using MIDAS Civil software, 24 finite-element models were developed to evaluate six deck curvatures (0m, 75m, 100m, 125m, 150m, 175m radii),[1] two pylon types (H-shape and single), and two cable systems (fan and harp). Key objectives include:

- Quantifying torsional responses, displacement patterns, and time-period variations under dead and live loads (IRC Class 70R).
- Assessing cable force redistribution and progressive collapse resistance after simulated cable loss.
- Identifying optimal pylon-cable configurations for curved spans to enhance redundancy and stability.

The findings reveal that deck curvature significantly amplifies torsional demands, with H-shape pylons and harp systems demonstrating superior load redistribution compared to single pylons and fan configurations. Inner cables near pylons exhibited lower force surges post-failure, highlighting their critical role in collapse resistance. These insights not only advance the theoretical understanding of curved cable-stayed systems but also provide actionable recommendations for engineers to optimize designs in complex geometries. By bridging the gap between academic research and practical application, this study advocates for updated design codes that prioritize curvature-aware modelling, redundancy strategies, and robust cable anchorage systems to safeguard against progressive collapse in modern bridge engineering

## 2. Methodology

The methodology encompasses a comparative analysis of cable-stayed bridge configurations using Midas Civil software, focusing on the influence of pylon geometry, cable arrangement, and deck curvature on structural performance. A total of 24 numerical models are developed, incorporating two pylon types (H-shaped and single) and two cable geometries (fan and harp) across six deck configurations: five horizontally curved radii (75m, 100m, 125m, 150m, 175m) and a straight deck.

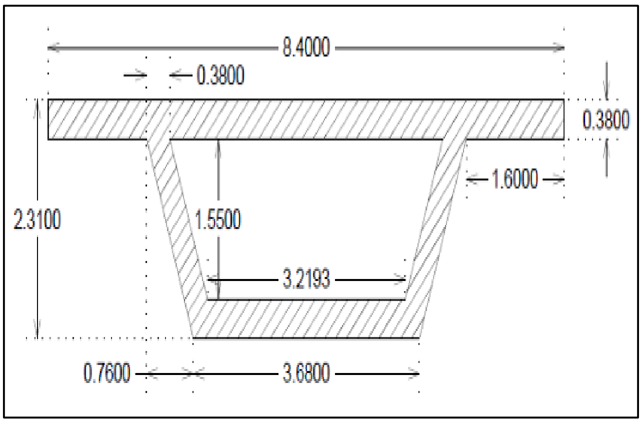


**Figure 1.** Deck cross section dimension

The deck comprises a 50m-span box girder with predefined sectional properties, constructed using M50-grade concrete. Pylons are modelled as 2.2m × 2.2m box sections, positioned at mid-span with heights of 12m (above deck) [10] and 8m (below deck), interconnected by an 8m-high cross beam. Rigid connection at pylon end and pin connection at deck end applied with elastic link. Cables (DG-p37 type, 5100mm² cross-sectional area) [9] are pretensioned to minimize deflection, optimized via the software's unknown load factor and cable force tuning features. Loading conditions include dead loads (fixed and variable superimposed loads, such as 1.65 kN/m² wearing coat) and live loads per IRC 6 Class 70R [1] standards, applied for moving vehicle analysis. A cable loss scenario evaluates force redistribution by sequentially removing cables under static critical loading. The study concludes with a comparative assessment of structural responses across curvatures, emphasizing deflection, stress distribution, and load-carrying efficiency to identify optimal configurations for curved cable-stayed bridges.

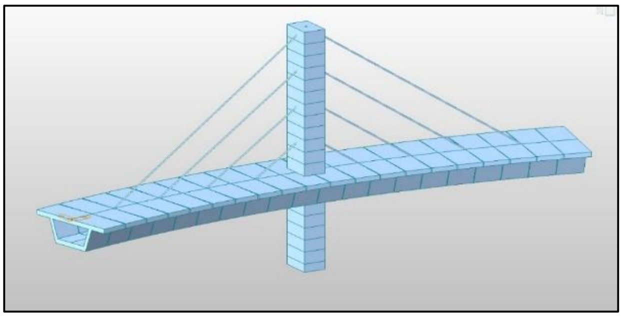

**Figure 2.** Single pylon bridge model

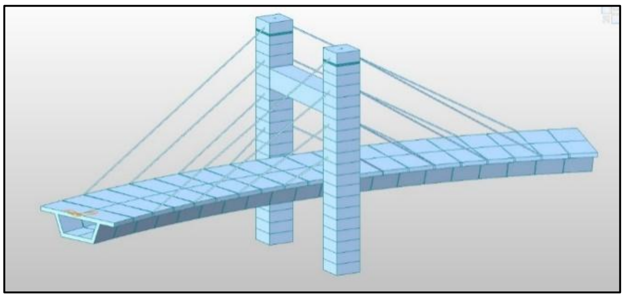

**Figure 3.** H shape pylon bridge model

## 3. Analysis Parameter Comparison

*3.1. Torsional behavior*: Single Pylon Systems: Torsion values in straight decks were negligible but increased significantly as the deck curvature radius decreased (Figure 4-5). For radii 75m, torsion peaked at ±1100 kN·m near mid-span, with positive and negative values distributed asymmetrically across the deck. Cable geometry (fan/harp) had minimal impact on torsional trends.

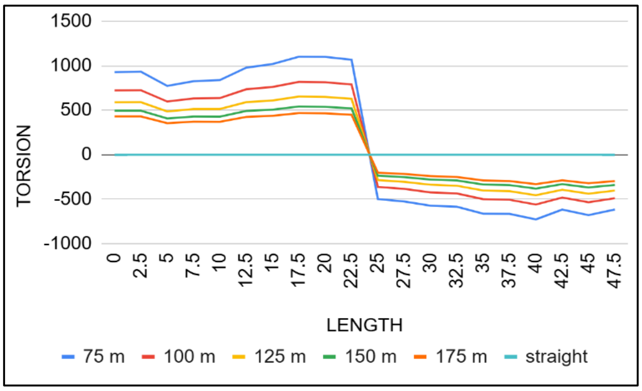


**Figure 4.** Torsion in single pylon, fan cable sys deck

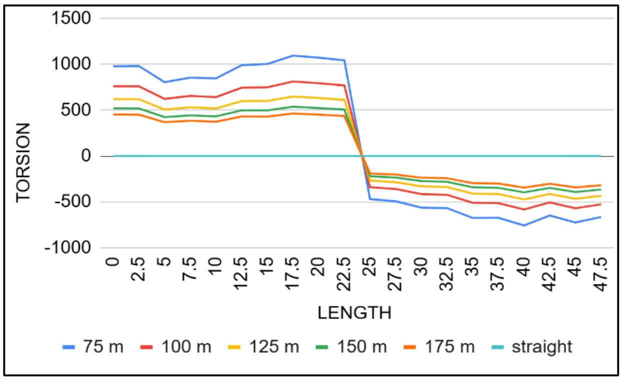


**Figure 5.** Torsion in single pylon, harp cable sys deck

*3.1.1 H-shape pylon systems:* Unlike single pylons, H-shape configurations exhibited higher torsional resistance. Torsion increased significantly in curved decks compared to straight ones (Figure 6-7). Fan cable systems induced 12% greater torsion than harp systems due to concentrated cable anchorage at the pylon top, amplifying transverse bending.

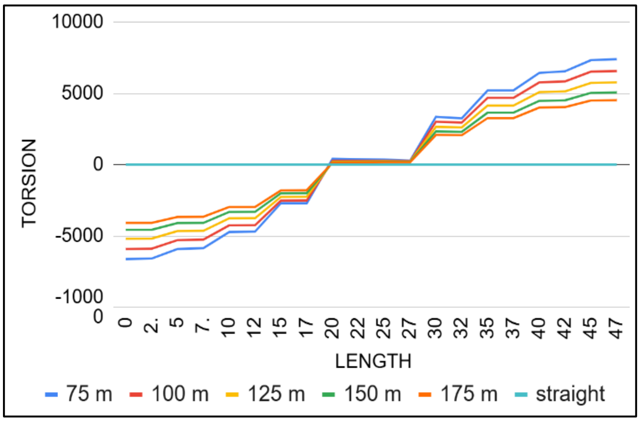


**Figure 6.** Torsion in h shape pylon, fan cable sys deck

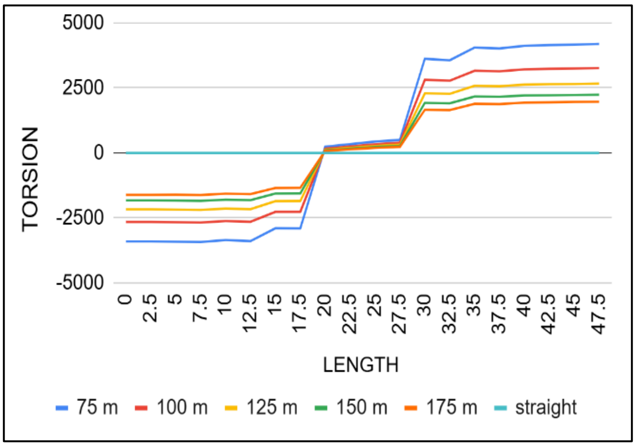


**Figure 7.** Torsion in h shape pylon, harp cable sys deck

*3.2. Moment distribution:*

*3.2.1 Y-direction moments (longitudinal):*

*3.2.1.1 Single pylon:* Moments increased linearly with curvature, peaking for a 75m radius deck (Figure 8-9). Fan systems showed marginally higher moments than harp systems (4–6% difference).

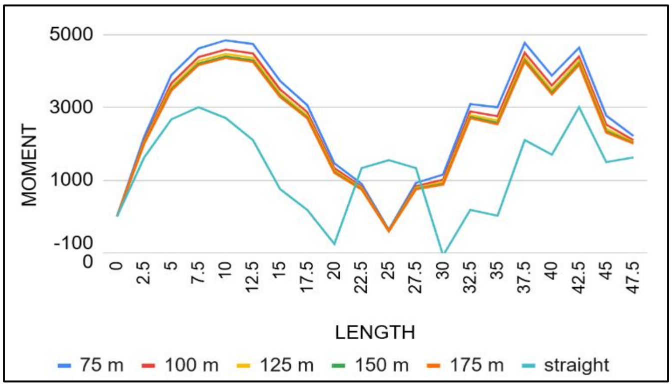


**Figure 8.** Y-direction moment in single pylon fan cable sys

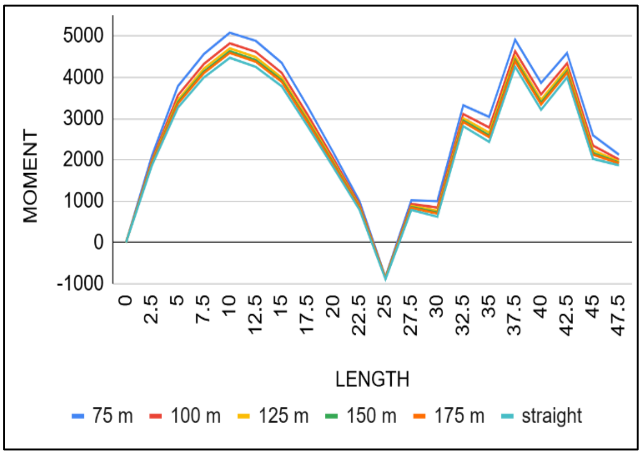


**Figure 9.** Direction moment in single pylon harp cable sys

*3.2.1.2 H-shape pylon:* Moments decreased by 15–20% in curved decks compared to straight configurations. Harp systems exhibited better load distribution, reducing peak moments by 10% (Figure 10-11).

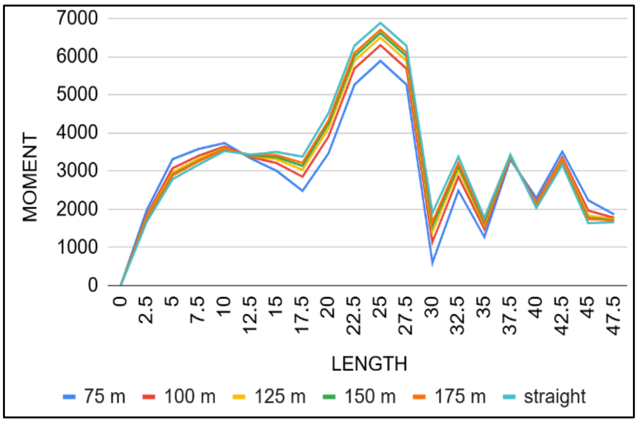


**Figure 10.** Y direction moment in single pylon harp cable sys

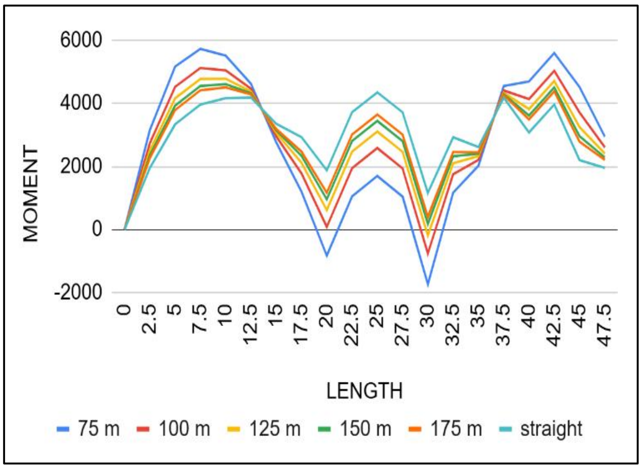


**Figure 11.** Y-direction moment in h shape pylon fan cable

*3.2.2. Z-direction moments (rotational):* Curved decks induced significant transverse moments, with maximum values at mid-span. H-shape pylons reduced Z-moments by 25% compared to single pylons due to cross-beam stiffness (Figure 12-13). harp cable system gives more controlled moments compare to fan cable system.

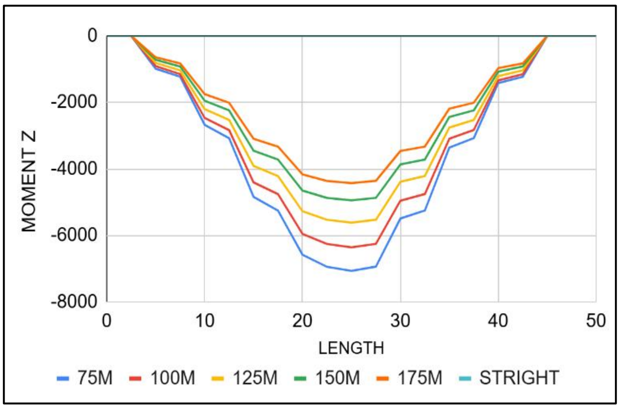


**Figure 12.** Z direction moment in h shape pylon fan cable sys deck

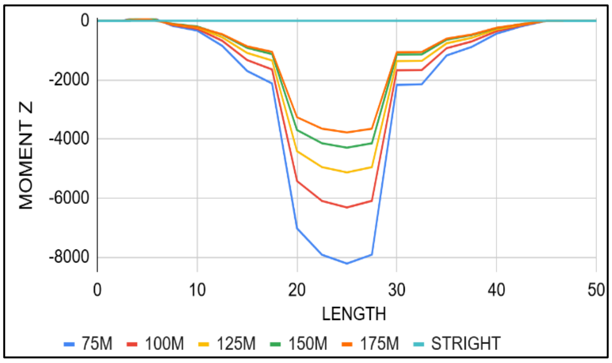


**Figure 13.** Z direction moment in h shape pylon harp cable sys deck

*3.3. Displacements:*

*3.3.1. Y-direction (horizontal):* Displacements increased with curvature, reaching 107mm for 75m radius decks in h shape pylon systems. It is due to same pretention force applied on all curvature. harp systems performing better than fan systems (Figure 14).

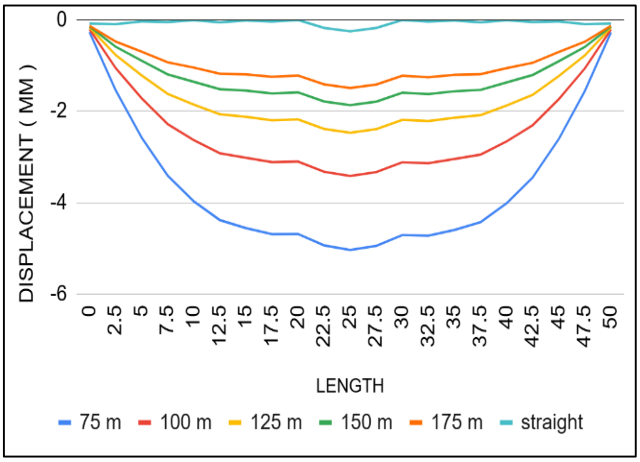


**Figure 14.** Z direction displacement in h shape pylon fan sys

*3.3.2 Z-direction (vertical):* Lateral displacements peaked at 5mm for 75m radius decks. harp system has less and controlled displacement then fan system H-shape pylons mitigated lateral drift by 40% through enhanced torsional rigidity (Figure 15).

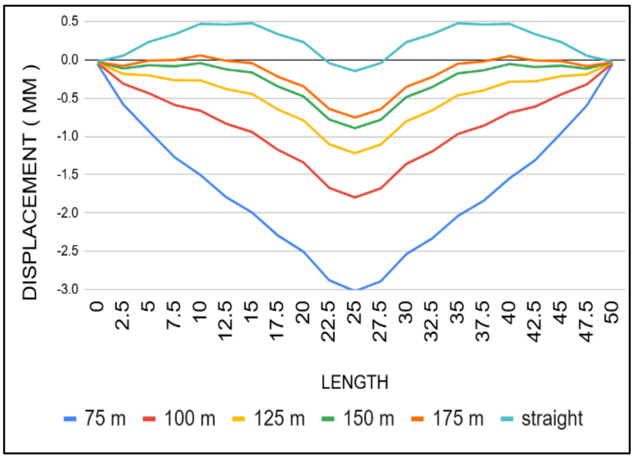


**Figure 15.** Z direction displacement in h shape pylon harp

*3.4 Cable force redistribution:*

*3.4.1 Fan vs. harp systems:* Fan systems redistributed forces more uniformly after cable loss, with adjacent cable forces increasing by 12–15%. Harp systems experienced sharper force spikes (18–22%) due to parallel cable geometry (Figure 16–19).

*3.4.2 Curvature impact:* Cables on the inner curvature side (radius ≤125m) carried 20–25% higher pretension forces. Loss of inner cables (e.g., Cable 4–5) caused 30% greater force redistribution than outer cables (Figure 18–19).

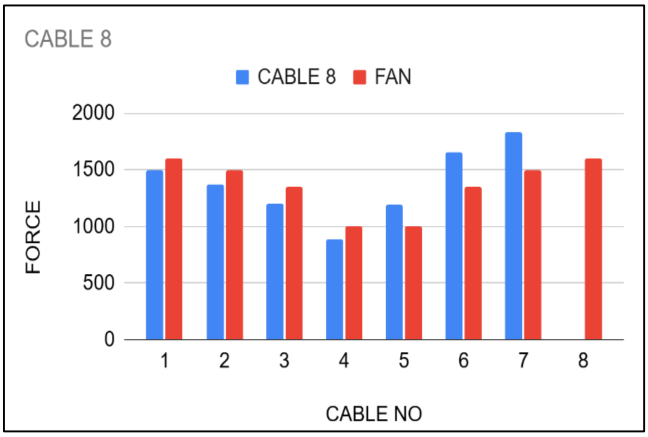


**Figure 16.** Cable loss in single pylon fan cable system 75m

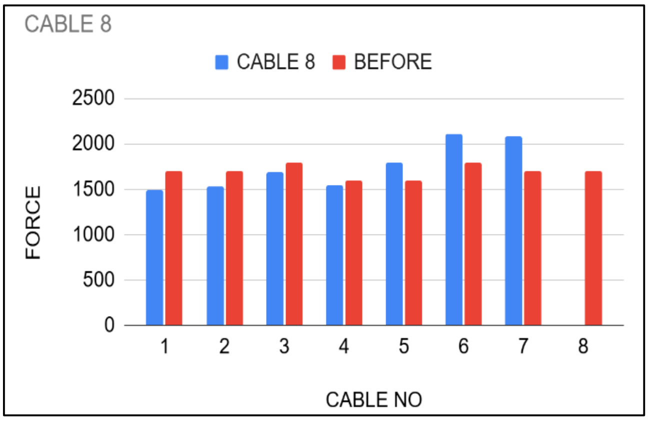


**Figure 17.** Cable loss in single pylon harp cable system 75m

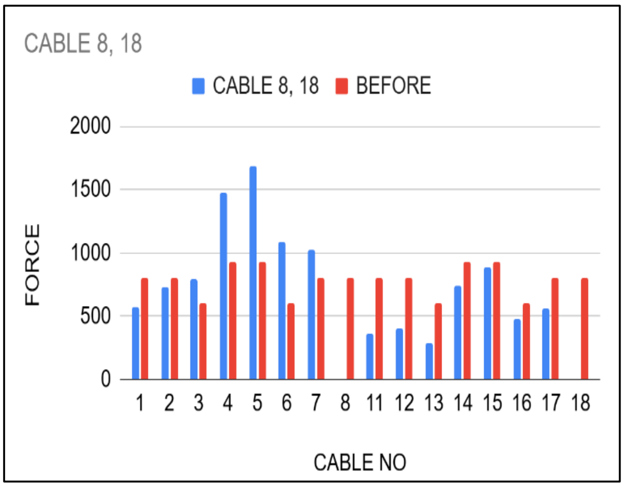


**Figure 18.** Double cable loss in H shape pylon fan sys 75m

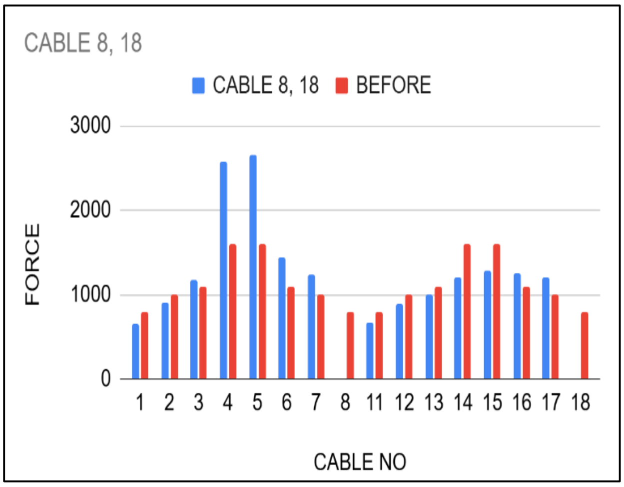


**Figure 19.** Double cable loss in H shape pylon harp sys 75m

*3.5 Time period analysis:* Single pylon systems had shorter natural periods (0.8–1.2s) compared to H-shape systems (1–2.8s), indicating lower stiffness. Curved decks slightly increased time periods (5–8%) due to added torsional flexibility. Harp systems reduced periods by 10% versus fan systems, suggesting superior dynamic stability (Figure 20–21).

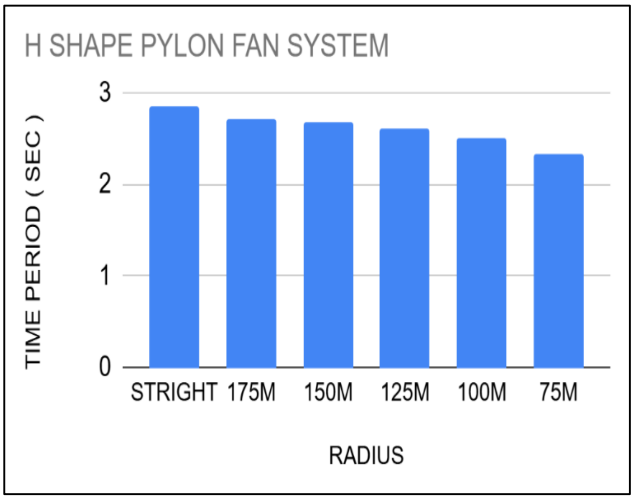


**Figure 20.** Time period in H shape pylon fan sys all radius

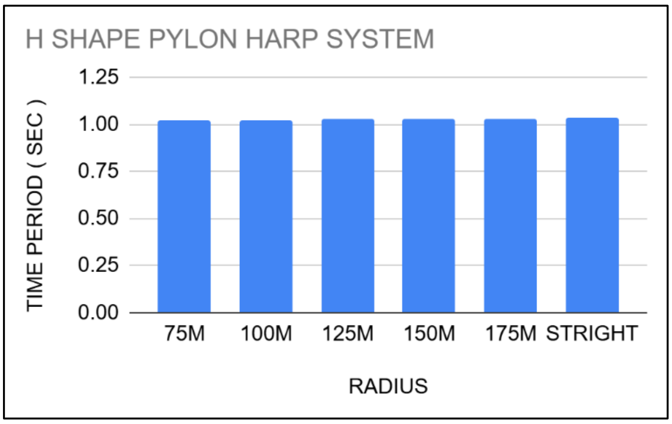


**Figure 21.** Time period in H shape pylon harp sys all radius

## 4. Progressive Collapse Resistance

*4.1 Single pylon:* Loss of end cables (Cable 1 or 10) caused 35% higher displacements than mid-span cable loss. Curvature had minimal impact on collapse resistance.

*4.2 H-shape pylon:* Proximity to the pylon determined collapse severity. Inner cable loss (Cable 4–5) triggered 40% greater force redistribution than outer cables. Curved decks (75m radius) showed 15% lower displacement thresholds, highlighting vulnerability under extreme curvature.(Figure 22)

*4.3 Cable system comparison:* Fan systems demonstrated 20% better redundancy than harp systems, as forces redistributed across multiple cables rather than localized zones.

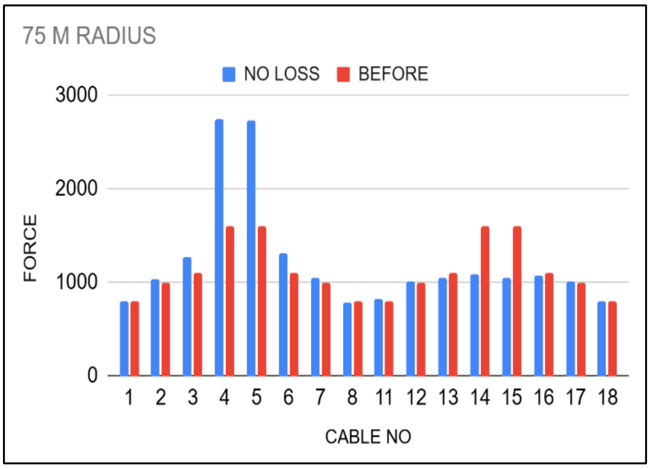


**Figure 22.** H shape pylon curvature effect on cable forces

## 5. Result Discussion

The study reveals that deck curvature significantly amplifies torsional and transverse moments, necessitating robust pylon designs. H-shape pylons outperformed single pylons in mitigating displacements and moments due to their cross-beam-enhanced stiffness. Fan cable systems, while inducing higher torsion, provided superior redundancy during progressive collapse, aligning with findings by Reis & Pedro (2001).[8].

The inverse relationship between curvature radius and structural stability underscores the need for curvature-specific design guidelines, absent in current IRC codes. Harp systems, though stiffer dynamically, exhibited vulnerability under cable loss, validating Sreerag & Singh's (2021) observations on pylon geometry impacts.[5].

Notably, inner curvature cables (e.g., Cable 4–5) emerged as critical failure points, suggesting targeted reinforcement for curved decks. The negligible impact of curvature on single pylon collapse resistance implies simpler geometries may suffice for low-curvature applications.

## 6. Conclusions

The study underscores the critical influence of deck curvature, pylon geometry, and cable arrangement on the structural performance of cable-stayed bridges. H-shape pylons, while stiffer, amplify torsional and displacement responses under curvature, making harp cable systems more suitable for curved decks due to their balanced load redistribution. Single pylons, though less torsionally rigid, may be advantageous in straight spans for their simplicity. Progressive collapse resistance improves when cable failures occur near pylons, as adjacent cables absorb forces more effectively. Fan systems, despite higher aesthetic appeal, exhibit vulnerabilities in curved configurations, necessitating stricter design checks. The findings advocate for IRC guidelines to address curvature-specific torsion and cable redundancy, prioritizing harp systems and H-pylons in complex geometries. This research provides a framework for optimizing cable-stayed bridge designs against progressive collapse, emphasizing curvature-aware modelling and strategic cable anchorage in future projects.

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