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# **Foot Over Bridge Health Monitoring with Reliable Solution for Retrofitting**

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**ABSTRACT:** Foot Over Bridges (FOBs) play a crucial role in ensuring pedestrian safety by facilitating movement over roads and railway tracks. However, many existing FOBs are experiencing deterioration due to aging, increased pedestrian load, environmental exposure, corrosion of steel members, and inadequate maintenance practices. Conventional visual inspection methods are often insufficient to detect internal damage and early-stage structural deficiencies, thereby increasing the risk of serviceability issues and structural failure. This project presents a comprehensive structural health assessment and retrofitting study of an existing Foot Over Bridge, with a detailed case study of the Kalyan (West) Skywalk. The study integrates visual inspection, non-destructive testing (NDT) techniques, and structural health monitoring (SHM) methods to evaluate the current condition of the bridge. Various NDT methods such as ultrasonic testing, dye penetrant testing, and thickness measurement are used to identify corrosion, cracking, section loss, and excessive deflection in critical steel components.

**KEYWORDS:** Staad Pro. Foot Over Bridge (FOB), Retrofitting, Bridge Health Evaluation

## **I. INTRODUCTION**

Structural Health Monitoring (SHM) is recognized as one of the best ways to increase general safety and optimize bridge operation and maintenance activities.

In my research project, the structure under inspection, the Kalyan West Skywalk, is a composite structure constructed by the Mumbai Metropolitan Region Development Authority (MMRDA), located in Kalyan, Maharashtra, to the North-West side of Thane railway junction. The skywalk is currently under Kalyan Dombivali Municipal Corporation (KDMC)'s management.



Fig: 1 Foot over Bridge, Kalyan

This chapter defines and describes the components and systems commercially available to monitor bridge health. In addition to different types of sensing systems, there are other terms applicable to bridge health monitoring that are also

defined. It is important for the user to understand the terms related to health monitoring, as well as the methods and capabilities of the various sensing systems, when choosing a system to meet the bridge needs. A glossary is included in this chapter, the goal of which is to define terms used in the development of the health monitoring system criteria. The glossary consists of four sections. The first two sections define structural health monitoring, as well as different terms used to describe the implementation of the system and how it will be used. The next section, titled “Monitoring Metrics”, defines the quantities that can be measured using commercially available health monitoring systems. For the final section of the glossary, a literature review was conducted. The information gathered was used to describe the theory behind each sensing system, what it measures, how it is applied in health monitoring applications, and possible advantages and disadvantages.

## II. LITERATURE SURVEY

Structural health assessment of bridge structures has gained significant attention in recent years. [1] Bertalmio et al. emphasized the importance of early damage detection to prevent catastrophic failures. [2] Several researchers have highlighted the effectiveness of NDT techniques in identifying hidden defects in steel structures.

[3] Ultrasonic thickness measurement has been widely used for quantifying corrosion-induced section loss in steel bridges. Acoustic emission techniques have proven effective in detecting crack initiation and propagation under live loading conditions. [4] Load testing combined with analytical modelling has been used to validate structural performance and remaining load-carrying capacity.

[5] Finite element modelling using software such as STAAD Pro and ANSYS has become a standard practice for re-analysis of existing structures by incorporating material degradation factors. [6] Retrofitting techniques such as section strengthening, corrosion protection systems, and load redistribution measures have been proposed by various researchers to enhance the service life of aging bridges.

However, limited studies present an integrated methodology combining NDT, SHM, load testing, and finite element re-analysis specifically for Foot Over Bridges. This study aims to address this gap.

## III. OBJECTIVES OF THE STUDY

The primary objectives of the present study are:

- To assess the existing condition of a Foot Over Bridge through visual inspection and non-destructive testing.
- To evaluate structural performance using static and dynamic load testing.
- To develop a finite element model incorporating observed thickness reduction.
- To identify critical structural deficiencies.
- To propose suitable retrofitting and strengthening measures.

## IV. METHODOLOGY

The methodology adopted for the structural health evaluation of the Foot Over Bridge is illustrated in Figure 1 and described in detail below.

- A. Case Study Selection: An existing steel Foot Over Bridge located in an urban environment was selected for the study. The bridge is subjected to heavy pedestrian usage and has been in service for several decades.
- B. Collection of Structural and Service Data: Available design drawings, material specifications, construction details, age of the structure, and maintenance history were collected. Site usage patterns and environmental exposure conditions were also documented.
- C. Visual Condition Assessment: A detailed visual inspection was carried out to identify visible signs of distress such as corrosion, paint peeling, deformation of members, cracking in connections, and condition of handrails and deck elements.
- D. Non-Destructive Testing: The following NDT techniques were employed:
  - 1) Dye Penetration Test (DPT): To detect surface cracks in welded joints.
  - 2) Ultrasonic Thickness Measurement: To quantify corrosion-induced thickness reduction in steel members.
  - 3) Magnetic Particle / Radiographic Testing: To detect subsurface flaws.

4) Acoustic Emission Testing: To monitor crack activity under loading.

E. Structural Health Monitoring: Sensors were installed to measure vibration response, displacement, and environmental parameters such as temperature and humidity. Data was recorded under normal pedestrian loading conditions.

F. Load Testing: Static and dynamic load tests were conducted using controlled pedestrian loads. Deflection and vibration responses were measured and compared with permissible limits.

G. Structural Performance Evaluation: The collected data was analysed to evaluate strength, stiffness, and serviceability of the structure.

H. Finite Element Modelling and Re-analysis: A three-dimensional finite element model was developed using STAAD Pro. Thickness reduction factors obtained from NDT results were incorporated into the model to simulate actual structural conditions.

I. Identification of Structural Deficiencies: Critical members exhibiting excessive stress, deflection, or section loss were identified based on analysis results.

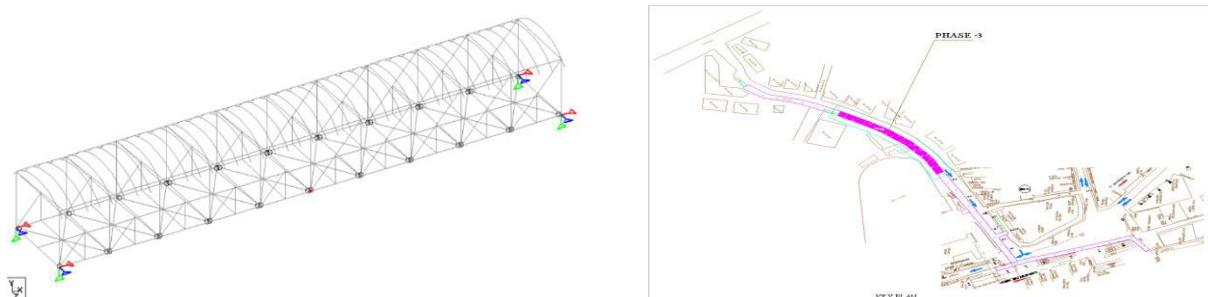
J. Retrofitting and Strengthening Measures: Based on the identified deficiencies, suitable retrofitting measures such as anti-corrosion treatment, section strengthening, and deflection control methods were proposed.

## **V. EXPERIMENTAL PROGRAM**

### **Actual Test**

Visual inspection is one of the most common methods used for evaluating the condition of a FOB. This method involves direct observation and assessment of the structure for signs of damage, corrosion, cracks, and other visible defects that may compromise its stability.

Visual inspection for FOBs is based on a combination of human expertise and structured assessment techniques.

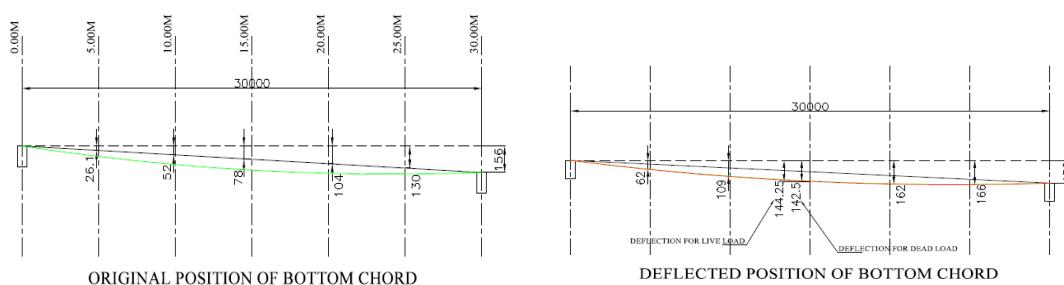


**FIG: 2 (A) FOOT OVER BRIDGE, KALYAN, (B) SKYWALK DETAILS**

### **Deflection**

Example: For a 30 m span: Vertical Deflection: Theoretical condition by using STAAD Pro., Max Allowable Deflection=L/250

Where L = span length in mm. Max Deflection=30000/250=120 mm



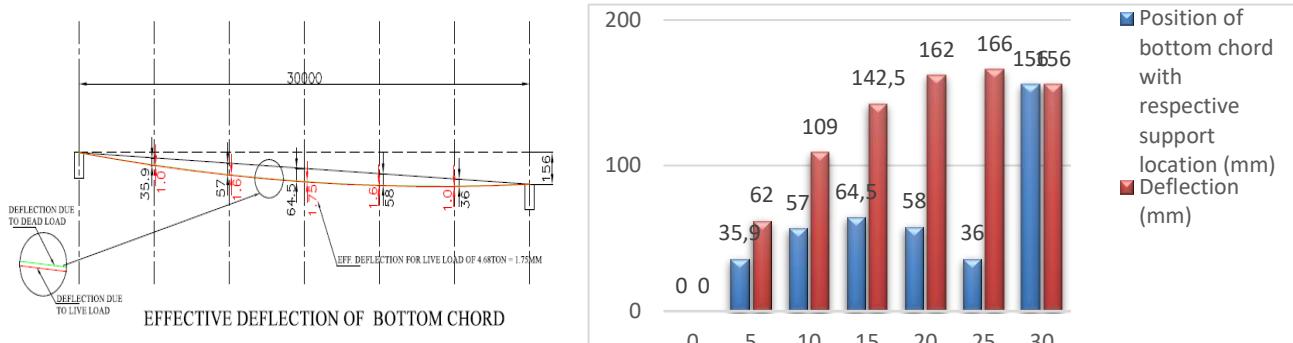
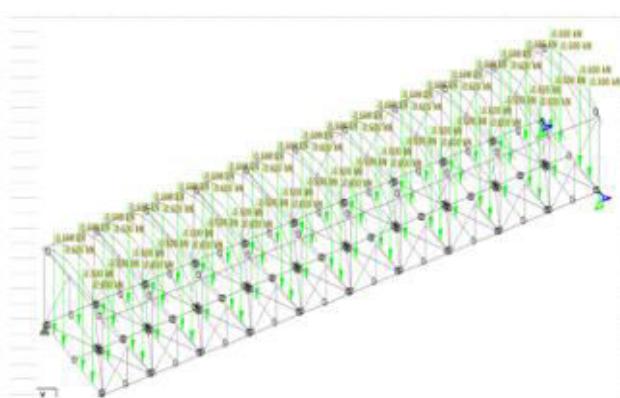


Fig: 3 (a) Deflected position of bottom chord, (b) Original position of bottom chord, (c) Effective deflection of bottom chord, and (d) Position of Maximum deflection

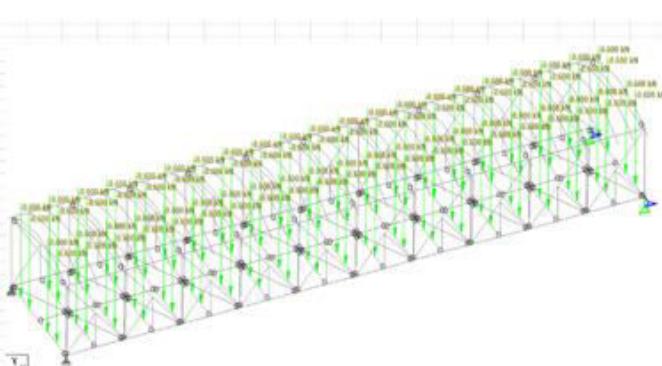
#### Deflection for Live Load from STAAD Pro.

##### Case-I



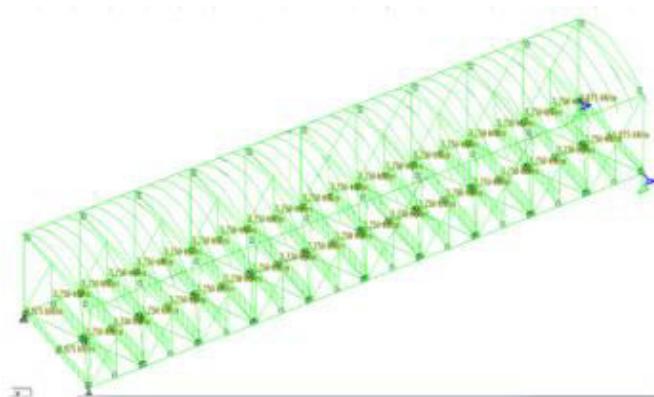
Deflection for LL - 3.00ton. (Equally distributed)					
	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm
Max X	1414	4 LL ON A6	0.206	-0.026	-0.036
Min X	1465	4 LL ON A6	-0.029	-0.026	-0.035
Max Y	978	4 LL ON A6	0	0	0
Min Y	1028	4 LL ON A6	0.088	-0.886	-0.043
Max Z	978	4 LL ON A6	0	0	0
Min Z	1028	4 LL ON A6	0.088	-0.886	-0.043
Max rX	1417	4 LL ON A6	0.203	-0.092	-0.037
Min rX	1092	4 LL ON A6	0.073	-0.875	-0.043
Max rY	1042	4 LL ON A6	0.009	-0.402	-0.004
Min rY	1467	4 LL ON A6	0.174	-0.132	-0.002
Max rZ	1467	4 LL ON A6	0.174	-0.132	-0.002
Min rZ	1416	4 LL ON A6	0.001	-0.133	-0.001
Max Rst	1028	4 LL ON A6	0.088	-0.886	-0.043

##### Case-II



Deflection for LL - 4.68ton. (Equally distributed)					
	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm
Max X	1411	4 LL ON A6	0.289	-0.038	-0.006
Min X	1462	4 LL ON A6	-0.047	-0.038	-0.006
Max Y	978	4 LL ON A6	0	0	0
Min Y	1001	4 LL ON A6	0.121	-1.26	-0.007
Max Z	987	4 LL ON A6	0.081	-1.195	0.001
Min Z	1028	4 LL ON A6	0.12	-1.242	-0.008
Max rX	980	4 LL ON A6	0.12	-1.242	-0.005
Min rX	989	4 LL ON A6	0.121	-1.26	0.001
Max rY	1042	4 LL ON A6	0.01	-0.565	-0.001
Min rY	1055	4 LL ON A6	0.231	-0.564	-0.001
Max rZ	1460	4 LL ON A6	0.241	-0.191	0
Min rZ	1410	4 LL ON A6	0.001	-0.19	0
Max Rst	1001	4 LL ON A6	0.121	-1.26	-0.007

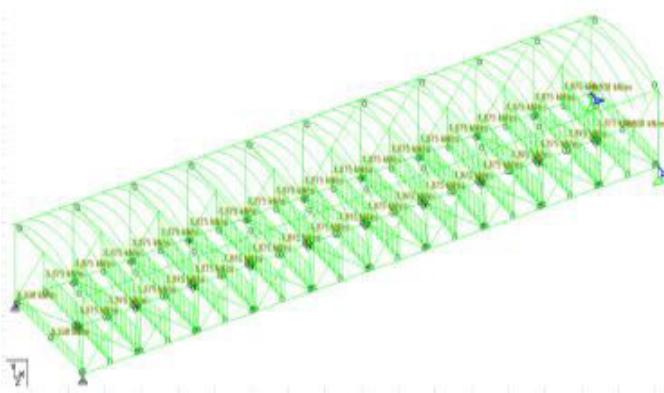
**Case-III**



Deflection for LL -25% of Design Live Load. (Equally distributed)

	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm
Max X	1414	4 LL ON A6	1.37	-0.178	0
Min X	1465	4 LL ON A6	-0.22	-0.178	0
Max Y	978	4 LL ON A6	0	0	0
Min Y	1028	4 LL ON A6	0.575	-5.962	0
Max Z	978	4 LL ON A6	0	0	0
Min Z	980	4 LL ON A6	0.575	-5.962	-0.016
Max rX	980	4 LL ON A6	0.575	-5.962	-0.016
Min rX	1048	4 LL ON A6	0.48	-5.902	-0.004
Max rY	1065	4 LL ON A6	0.731	-4.146	-0.005
Min rY	1070	4 LL ON A6	0.419	-4.146	-0.005
Max rZ	1467	4 LL ON A6	1.146	-0.901	-0.001
Min rZ	1416	4 LL ON A6	0.004	-0.901	-0.001
Max Rst	1028	4 LL ON A6	0.575	-5.962	0

**Case-IV**

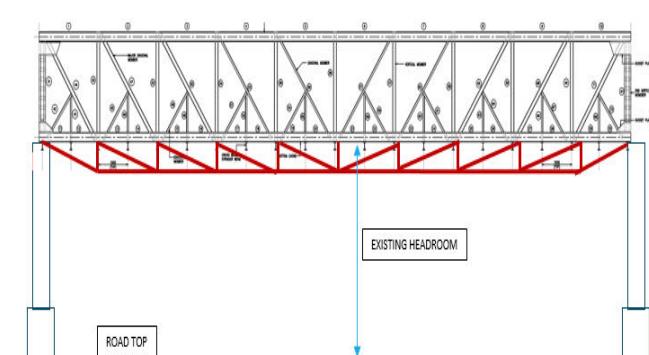


Deflection for LL - 50% of Design Live Load. (Equally distributed)

	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm
Max X	1414	4 LL ON A6	2.74	-0.357	0
Min X	1465	4 LL ON A6	-0.441	-0.357	0
Max Y	978	4 LL ON A6	0	0	0
Min Y	1028	4 LL ON A6	1.15	-11.924	0
Max Z	978	4 LL ON A6	0	0	0
Min Z	980	4 LL ON A6	1.15	-11.924	-0.033
Max rX	980	4 LL ON A6	1.15	-11.924	-0.033
Min rX	1048	4 LL ON A6	0.959	-11.803	-0.008
Max rY	1065	4 LL ON A6	1.463	-8.293	-0.01
Min rY	1070	4 LL ON A6	0.837	-8.293	-0.01
Max rZ	1467	4 LL ON A6	2.291	-1.802	-0.001
Min rZ	1416	4 LL ON A6	0.008	-1.802	-0.001
Max Rst	1028	4 LL ON A6	1.15	-11.924	0

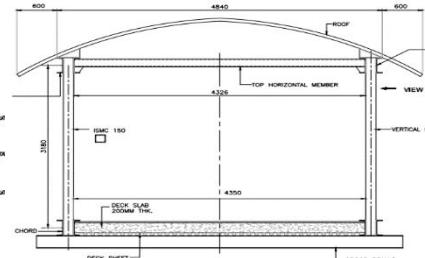
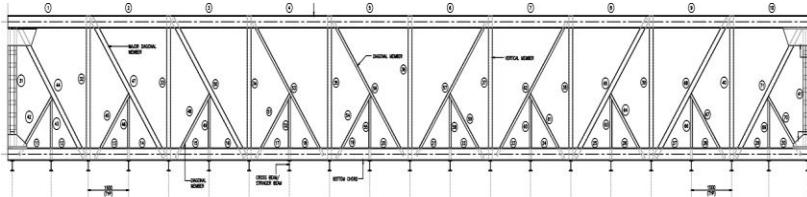
**Different Remedial Action Taken to Overcome the Deflection**

**Option 1 – Additional frame below**



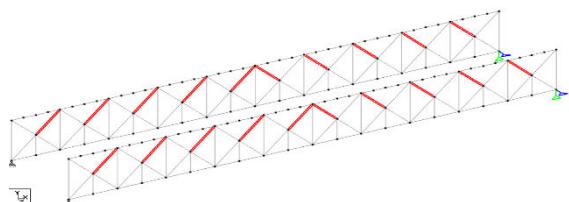
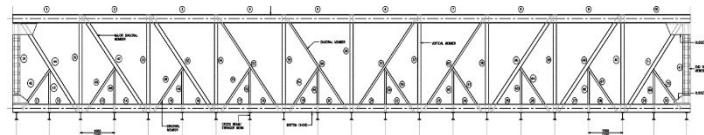
	Node	L/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm	Resultant mm	Rotational rX rad	Rotational rY rad	Rotational rZ rad
Max X	1411	3 DEAD LOAD	8.539	-0.702	-0.006	8.568	0	0	-0.003
Min X	1462	3 DEAD LOAD	-0.528	-0.702	-0.006	0.878	0	0	0.003
Max Y	978	3 DEAD LOAD	0	0	0	0	0	0	-0.004
Min Y	989	3 DEAD LOAD	4.005	-31.438	0.105	31.693	0	0	0
Max Z	989	3 DEAD LOAD	4.005	-31.438	0.105	31.693	0	0	0
Min Z	980	3 DEAD LOAD	4.005	-31.438	-0.105	31.692	0	0	0
Max rX	1472	3 DEAD LOAD	-0.388	-5.508	-0.043	5.521	0	0	0.003
Min rX	1421	3 DEAD LOAD	8.399	-5.508	0.043	10.044	0	0	-0.003
Max rY	1465	3 DEAD LOAD	-0.528	-0.702	0.006	0.878	0	0	0.003
Min rY	1414	3 DEAD LOAD	8.539	-0.702	0.006	8.568	0	0	-0.003
Max rZ	1461	3 DEAD LOAD	8.01	0	0	8.01	0	0	0.004
Min rZ	978	3 DEAD LOAD	0	0	0	0	0	0	-0.004
Max Rst	989	3 DEAD LOAD	4.005	-31.438	0.105	31.693	0	0	0

**Option 2 – Additional member in Top & Bottom Chord**

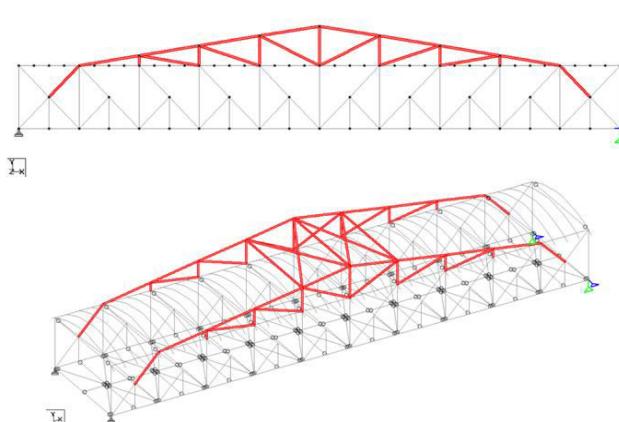


Option 3 – Additional Vertical member in N Girder

Option 4 – Additional frame on top of girder



## VI. RESULT



	Node	I/C	Horizontal X mm	Vertical Y mm	Horizontal Z mm	Resultant mm	rx rad	ry rad	rz rad
Max X	1461	3 DEAD LOAD	6.918	0	0	6.918	0	0	0.003
Min X	978	3 DEAD LOAD	0	0	0	0	0	0	-0.003
Max Y	978	3 DEAD LOAD	0	0	0	0	0	0	-0.003
Min Y	988	3 DEAD LOAD	2.953	-22.817	0.021	23.008	0	0	0
Max Z	1594	3 DEAD LOAD	3.459	-22.279	0.16	22.546	-0.001	0	0
Min Z	1609	3 DEAD LOAD	3.459	-22.279	-0.16	22.546	0.001	0	0
Max rx	1609	3 DEAD LOAD	3.459	-22.279	-0.16	22.546	0.001	0	0
Min rx	1594	3 DEAD LOAD	3.459	-22.279	0.16	22.546	-0.001	0	0
Max ry	1411	3 DEAD LOAD	5.649	-0.608	-0.006	5.682	0	0	-0.002
Min ry	1462	3 DEAD LOAD	1.269	-0.608	-0.006	1.407	0	0	0.002
Max rz	1461	3 DEAD LOAD	6.918	0	0	6.918	0	0	0.003
Min rz	979	3 DEAD LOAD	0	0	0	0	0	0	-0.003
Max Rst	990	3 DEAD LOAD	3.966	-22.817	0.021	23.159	0	0	0

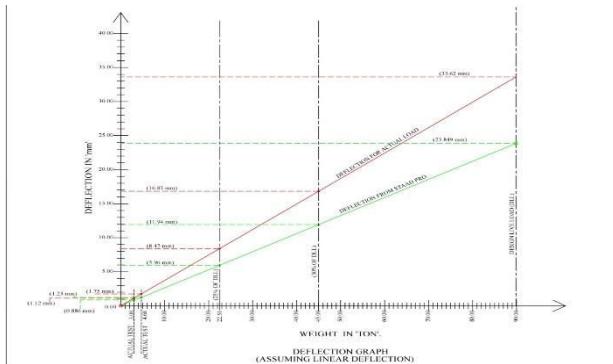
Following are the results outcome from our experimental program.

Maximum deflection for dad load is **37.501mm**

Maximum deflection for live load from STAAD pro. Is **23.849mm**

Actual deflection on site for dead load is **64.5mm**.

Actual deflection on site & STAAAd Pro. For live load as follows.



Sr. No.	Total Wt. (Ton)	Deflection from STAAD (mm)	Deflection on site / (linear graph) (mm)	Remark
1	$60 \times 78 = 4.68$	1.26	1.75	Defl. On field & STAAD.
2	$60 \times 50 = 3.00$	0.886	1.02	
3	22.5(25% DLL)	5.96	9.44	Defl. From Line graph.
4	45(50% DLL)	11.94	19.27	
5	90(DLL)	23.849	38.740	

Fig: 4 (a) Graphical representation for Actual Deflection On Site & Staad Pro. For Live Load, (b) Deflection for Live Load of different Cases

## VII. CONCLUSION

- 1] The measured deflection of the skywalk bridge under both cases dead load and live load is increased, which exceeds the allowable deflection limits prescribed by standard design codes. This excessive deflection indicates that the structure is not performing as intended and may be experiencing inadequate stiffness, material deterioration, or under-designed structural elements.
- 2] Therefore, the skywalk bridge cannot be considered safe in its current condition. Immediate actions such as restricting access, conducting a detailed structural investigation, and implementing necessary strengthening or rehabilitation measures are required to prevent further deterioration and reduce the risk of structural failure.
- 3] To ensure long-term performance and public safety, it is recommended to adopt a smart, scalable SHM system integrated with a predictive maintenance framework. This approach allows infrastructure managers to implement reliable, non-disruptive retrofitting measures, extending the life span of foot over bridges while minimizing lifecycle costs and disruptions.

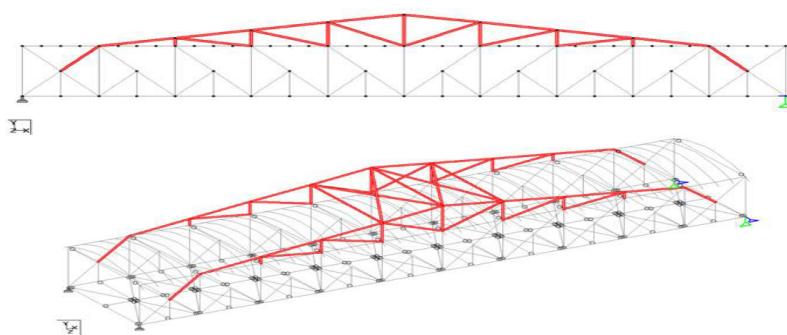


Fig: 4 The Adopted New Frame on Top of Girder to Control Further Deflection

4] Effective health monitoring of foot over bridges (FOBs) is essential to ensure public safety, extend service life, and optimize maintenance costs. The integration of reliable monitoring systems provides early warnings of structural degradation, allowing for timely and targeted retrofitting.

5] Installing a new frame above the girder increases the girder's moment of inertia, which helps control additional deflection. In addition, the frame enhances the overall aesthetic appearance of the bridge.

## Retrofitting Strategy

The following retrofitting measures were proposed:

- Addition of 6 mm C-shaped steel plates to strengthen corroded beams.

- Application of anti-corrosion coatings and protective paint systems.
- Replacement of severely damaged bolts and connections.
- Improvement of drainage to reduce future corrosion.

### Future Scope

Future studies may incorporate long-term monitoring systems, advanced corrosion modeling, and life-cycle cost analysis to optimize maintenance strategies for Foot Over Bridges.

1) Smart and AI-Driven Monitoring Systems:

- Development of AI and machine learning algorithms to detect, predict, and classify damage in real-time.
- Use of edge computing and IoT-enabled sensors for decentralized, low-latency data processing.
- Predictive maintenance models that anticipate failures before they occur, optimizing intervention timing.

2) Autonomous Inspection Technologies:

- Use of drones, robotic crawlers, and automated camera systems for close-up visual inspection and thermal imaging.
- Reduces human risk, improves inspection accuracy, and supports frequent monitoring.

3) Advanced Retrofitting Materials and Techniques:

- Development of next-generation materials like self-healing concrete, ultra-high-performance fiber-reinforced concrete (UHPFRC), and graphene-enhanced composites.
- Modular and fast-installation retrofit systems for minimal traffic or pedestrian disruption.

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