Bridge Health monitoring systems using Drones and AI

Project Supervisor

Col Dr. Adeel Zafar

Project Co- Supervisor

Dr. Safi Ur Rehman

Syndicate members:

CMS ID: 325530	Ahmed bin Abdul Rauf (SND LDR)
CMS ID: 325536	Muhammad Hamza
CMS ID: 325487	Ahmad Imran Raja
CMS ID: 325491	Muhammad Haris
CMS ID: 325481	Danish Khan
CMS ID: 325486	Asadullah Naseer

NATIONAL UNVERSITY OF SCIENCES AND TECHNOLOGY

MILITARY COLLEGE OF ENGINEERING RISALPUR

RISALPUR CAMPUS, PAKISTAN

(2023)

DECLARATION

I certify that this research work titled –"**Bridge Health Monitoring System using drones and AI**" is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources has been properly acknowledged / referred.

Signature of Student

Ahmed bin Abdul Rauf (SYN LDR)

CMS 325530

NUST

MCE, Risalpur

We dedicate this to our exceptional parents and adored siblings whose tremendous support and cooperation led us to this wonderful accomplishment.

ACKNOWLEDGEMENTS

We are thankful to our creator أَللّٰه عَزَّ وَ جَلَّ who has guided us throughout this work at every step and for every new thought which He set up in our minds to improve it. Indeed, we could have done nothing without His priceless help and guidance. Whosoever helped us throughout the course of our thesis, whether our parents or any other individual was His will, so indeed none be worthy of praise but Him.

We are profusely thankful to our beloved parents who raised us when we were not capable of walking and continued to support us in every chapter of our lives.

We would also like to express special thanks to our supervisor **Col Dr. Adeel Zafar** for his help throughout our thesis and for Design of Concrete Structures and other things which he has taught us during our project. We can safely say that we haven't learned any other engineering subject in such depth than the one which he has taught.

We would also like to pay special thanks to our CO advisor **Dr. Safi ur Rehman,** who has offered great assistance in terms of his presence, ideas, and support.

Last but not least, **Lab Engr Huzaifa** and his staff provided us with the NDT equipment and guided us throughout regarding the operations of these devices.

We appreciate their patience and guidance throughout the whole project work and thesis.

Finally, we would like to express our gratitude to all the individuals who have rendered valuable assistance to our work and study.

Table of Contents

Table of Figures

Abstract

Bridges have proven to be a remarkably effective civil engineering marvel in the past years. They, like everything else, have a life span as well. Once they are constructed and put into service, their deterioration commences. It is crucial to inspect bridges periodically to assess their structural strength and serviceability to ensure the safety of the users. To reduce the efforts, we will be experimenting with photogrammetry, drones and software that use AI to translate pictures into 3D models on a computer to be analyzed. The result will be to evaluate the capabilities and effectiveness of this model as bridge inspection tools to reduce the risk to life and economize the monitoring tasks so that it can be done more regularly and easily.

Chapter 1

1. Introduction

1.1 Background and context

Bridge inspection is an integral part of the bridge maintenance cycle. Current practice is a personal visual inspection of bridges (performed by an inspection team). Some parts of the bridge are accessible on foot, and some require the mobilization of heavy equipment, such as a platform connected to a crane on which an inspector inspects the bridge. The problem with this method is that it is tedious, involves a safety hazard, and can disrupt the operability of the bridge while the equipment is in place. In addition, each inspector subjectively reports conditions or damage, and it is very time-consuming. The result will vary from individual to individual. Thus, there is a need for an alternative method that uses the latest technology to address the drawbacks of conventional methods. One of the possible alternatives is the use of optical methods, especially the photogrammetric method. This method allows us to remotely capture data with drones in the form of images and process them into 3D for visualization. The use of this method is a relatively new and advanced concept in the construction industry, especially in bridge structures.

1.2 Inspection of Bridges

Bridge health monitoring is the process of regularly assessing the condition of a bridge to ensure its continued safety and functionality. Photogrammetry, the process of measuring and interpreting photographic images, is one of the techniques used in bridge health monitoring.

Bridge monitoring can be done in many ways, and it's traditionally done by walking or drive-by inspections. However, these types of inspections are time-consuming and labor-intensive, and they can be dangerous for the inspectors.

Photogrammetry offers an efficient and safe alternative. By using cameras, drones or other aerial platforms, engineers can capture high-resolution images of a bridge from multiple angles. These images can then be used to create 3D models of the bridge, which can be analyzed to identify any structural deformations or damage.

The benefits of photogrammetry are many. The images captured can be used to create 3D models using point clouds of the bridge, which can be analyzed for any deformations or damages, this can detect problems that would be difficult to spot during an in-person inspection. Additionally, photogrammetry allows for the monitoring of bridges over long periods of time, which can be used to detect changes in structural integrity over time.

Moreover, photogrammetry allows for remote monitoring, which eliminates the need for personnel to physically inspect the bridge, reducing the risk of accidents and improving overall safety. This technology can also be used to monitor multiple bridges simultaneously, which can save time and resources.

In conclusion, Photogrammetry is a powerful tool for bridge health monitoring. It allows engineers to assess the condition of a bridge, detect potential problems, and monitor changes over time safely and efficiently. The use of this technology is expected to increase as it continues to evolve and improve, and it will play a vital role in maintaining the safety and functionality of bridges for years to come.

1.3 Problem Statement

Bridges are live structures, which once constructed and put into service, deterioration commences due to repeated cycling loading, environmental effects, unpredictable hazards, and material degradation. Therefore, bridges are susceptible to wear and tear throughout their period. They as structures involve high public stakes, therefore it is crucial to inspect them, and assess their structural strength and serviceability to ensure the safety of the users. Bridges are designed to last a specific number of years, i.e., design life.

AASHTO requires bridge inspection to be conducted every 24 months, which is a very short time span to go through an extensive and intricate process. Traditionally, bridge inspections have been performed manually, using visual inspections and hammer testing to assess the condition of the structure. However, these methods have several limitations, including the potential for human error and the limited scope of information that can be gathered.

Certain environmental conditions coupled with the application of greater loads than the design load, take their toll on the structural health of the bridge, which calls for regular inspections and remedies that need to be carried out for a bridge to be deemed safe.

1.4 Scope/ AIM

The main aim of this project is to enhance the bridge inspection system in such a way that it uses the least number of resources to formulate the best possible results. To cut the operational costs and reduce risk to human safety by deploying advanced photogrammetry techniques. This will also be improvising on the uniform bridge evaluation and multiple opinions of various people about a single bridge can be adopted.

Chapter 2

2. Literature Review

2.1. General

Bridges are structures widely used in the transportation industry. They are built to span hindrances in the natural or manmade topography. This be due to lakes, valleys, or roads. The purpose is to provide a path for transport of vehicles or people. They connect communities and are an integral part of the transportation infrastructure.

The simplest types were seen six thousand years ago, steppingstones used to cross marshes by the nomadic people. They further evolved into timber structures. The use of concrete bridges was pioneered by the romans who famously built aqueducts which were built to withstand high environmental conditions. They have ever since been subject to evolution, further refining each aspect.

With exponentially increasing population of both humans and vehicles, the bridges struggle to cope up with the traffic volumes for which they are insufficiently designed, leading engineers to quantify the shortcomings and re-evaluate the performance of existing bridges. It has been estimated that 45% of bridges are currently deficient to either structural deterioration or traffic inadequacy. [1]

2.2. Non-destructive testing

Concrete is the most popular building material that is currently being used on the planet. The core quality of concrete as a building material is its compressive strength coupled with steel to handle tensile forces. Over time many researchers have developed various techniques that may or may not hamper the structure to check the strength and of the material e.g., destructive, and non-destructive tests.

Nondestructive tests detect flaws with minimal damages to the structure may it be of any kind.[2]

Artificial intelligence has enhanced NDTs in the following way.[2]

- Increased reliability and accuracy of NDTs
- Reduced cost and time of inspections
- Eased the process.

2.2.1. Schmidt Hammer

Also known as the Rebound Hammer is a quite common non-destructive test, used as a benchmark to evaluate concrete strength. It enjoys popularity because of the ease of execution and credibility of results, cost effectiveness and simplicity. The basic principle on which the device works is that a spring mass is rebounded, and the strength of the concrete is judged upon how much it is displaced on the rebound index scale. A detailed diagram of the apparatus is shown in figure 2.1. [3]

As per the Indian code IS: 13311(2)-1992, The objectives of the rebound (Schmidt) hammers are to correlate the rebound index with the compressive strength of concrete to a series of graphs and contemplate the uniformity of the concrete based on present specifications.

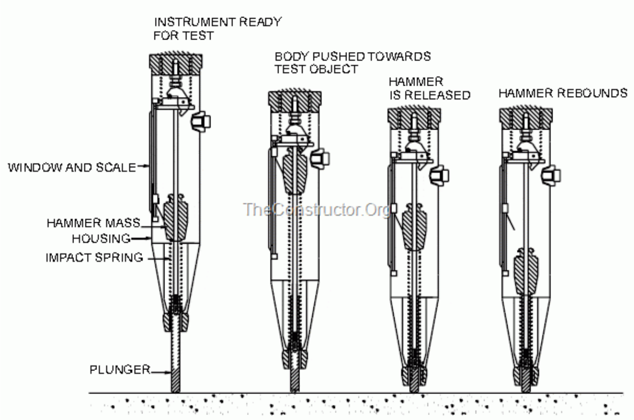


Figure 1 Schmidt Hammer

2.2.2. Rebar Scanner

Rebar scanners are devices that are used to scan and locate rebar locations and orientations for precast structures [4], and can be used to analyze the health of in situ casted RCC components. Which collectively include piers, and shafts for bridges etc. These scanners capable of high accuracy ranging and negligible time lag are used for structural health monitoring in addition to its other several uses.[5]

Figure 2 Rebar Scanner

2.2.3. Accelerometer

Deflections are a major concern in bridge health monitoring. Accelerometers have replaced manual calculations with measuring accelerations using electrical impulses generated by using time and displacement data from the movement caused in the structure.[6] Continuous improvement in calculation programs and data collection/delivery systems, interpreting huge amounts of data has enabled the device to be more accurate and precise.[7]

Figure 2 Accelerometer

2.3. Current bridge inspection practices

2.3.1. AASHTO Method

The manual for bridge evaluation (MBE) dictates the types of inspections:

1) Initial
2) Routine
3) Damage
4) In-depth
5) Fracture critical
6) Under water
7) Special (interim)

The frequency of inspection and periods are set according to the bridge's condition and past reports. The period between inspections should not exceed 24 months. The frequency of visits is done with reference to visual observations and any changes in dimensions in contrast to the dimensions mentioned in the original drawings.[8]

2.3.2. Federal highway authority (FHWA) (USA)

The policy has its own procedure for bridge inspection. This dictates that all bridges in all states be inspected once every 2 years. All structurally deficient bridges should be inspected annually. The procedure implies that a qualified bridge inspector arrives on-site and uses standard Performa to assess the bridge, any damage is reported by taking notes, sketches or via a clear picture of the singular defect. The checklist and other related data are uploaded to the Bridge monitoring systems (BMS). The report is then compared with past reports by inspectors. Any deficiencies are noted as per the past reports and retrofitted and remedied as per requirement.

2.3.3. National highway authority (NHA) method

NHA employs the same set procedures as per the AASHTO method, however, uses its own “Bridge inspection report” forms. The site is visited by NHA inspection crews, and the reports are then filed to the Road Asset Management Director (RAMD) and to the regional offices. The method is dependent upon the skill/experience of the inspector and their team. This qualitative method will create disparities in the reports as per the experience of each inspector.

2.4. Constraints in bridge evaluation methods

There are several problems faced by the administration and inspection teams. The major concern is accessibility. When inspecting a bridge’s under body, major safety risks are posed to both the team and equipment alike. The safety of the inspectors is jeopardized as soon as they step up on elevated platforms for inspection procedures. If proper scaffolding or bucket crane trucks are brought in, it will require more time and alleviate the cost of inspection by great margins. Many inspection forms ask to rate a component of the bridge from 0 to 100. This depends upon the judgement of the inspector and will vary from person to person due to the different environment or experience of the inspector.

The amount of information gained from these inspection crews is paper based. The management of this data and acquisition of the data at any required time is time taking and exhaustive.

2.4.1. Accessibility

The conventional methods used for bridge inspection according to AASHTO bridge evaluation manual are tall ladders, mechanical lift vehicles, under bridge crane vehicles, powerlift staging, rigging, scaffolding, boats, rope access climbing, and underwater diving equipment. All these pose risks to human life and raise serious health concerns of the team working. Also, the access techniques are resource, cost, and time extensive.

2.5. Photogrammetry

Photogrammetry is the art and science of extracting 3D information from photographs. The process involves taking overlapping photographs of an object, structures or space using manual and automatic techniques, and then converting them to 2d or 3d digital models. Photogrammetry technique involves determination of the objects size, shape, and location with respect to its surroundings.

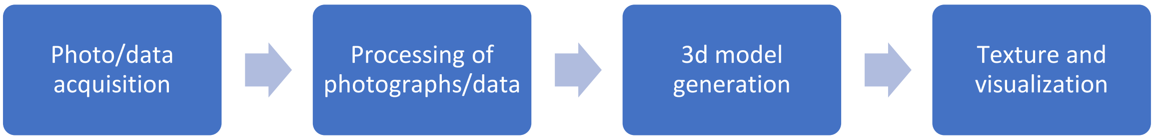


Figure 3 Photogrammetric inspection flow diagram

Furthermore, photogrammetry techniques, although not better than actual field survey, provide the next best alternative to bridge inspection.

Due to the availability of advanced, digital cameras of various sorts available in the market at reasonable costs, photogrammetry offers the best alternative to any other CAD based techniques used.[9]

2.5.1. Photo/Data acquisition

Data collected may be either hard copy photographs taken with film cameras or digital photographs taken with digital cameras or in our case using drones to capture photos.

2.5.2. Processing of photographs/Data, 3D Model generation.

The photographs are then imported into the photogrammetric modeling software where point clouds are created to represent a 3D shape or an object.

2.5.3. Texture and Visualization

3D model is just the line drawing or a set of point clouds giving the shape of an object that is photographed. To get the realistic impression of an object textures and details are added to that 3D model.

2.5.4. Cloud points

A point cloud is a discrete and unique set of data points in space, The primary purpose of point cloud is to create a 3d shape, object, or model.[10]

2.6. Types of defects in Bridges

2.6.1. Sub Surface Defects

Subsurface defects such as corrosion of reinforcement and concrete delamination are not visible, but these defects have a strong impact of reducing elements structural capacity and are very harmful to the entire structure.

2.6.2. Corrosion of steel reinforcement

The steel reinforcement damages due to electro chemical corrosion process. It usually appears as rust stain. At severe stages the concrete surface above reinforcement cracks delaminates, and spalls.

2.6.3. Concrete delamination

It is the separation of concrete layers along horizontal plains at or near the out most layer of reinforcing steel.

2.7. Surface defects

Surface defects are the deficiencies on the surface of concrete members such as cracks, spalling, scaling, efflorescence, and pop-outs.[11]

2.7.1. Cracking

It is the linear fracture in the concrete surface caused by tensile, compressive or shear stresses in concrete.

2.7.2. Concrete scaling and erosion

It is the disintegration in the concrete due to progression of physical deterioration. Scaling is local flaking or loss of surface mortar or concrete. Erosion is the detachment of concrete surface resulting from the friction of ice of water containing stones or gravel.

2.7.3. Spalling

It is complete separation of delaminated area from the concrete. The roughly circular or oval depression left is known as spall.

2.7.4. Deposits and efflorescence

Deposits are formed when water percolates through the concrete and dissolves leaches chemicals from it and deposits them on the surface. Deposits may appear as efflorescence.

2.8. Unmanned Aerial Vehicles

UAV (Unmanned aerial vehicle) is any vehicle which has the capability to travel through the air without touching the ground for a certain period. It is unmanned and is controlled through a remote device or has autonomous capabilities. A more common word used for UAV is ‘Drones’.

Figure 4 UAV/Drone

2.9. Load Rating

The load rating of a bridge is a very vital aspect when it comes to safety and maintenance of the structure. Load rating is done to determine the live load (vehicles and pedestrians) capacity of the bridge without significant deflections/defects caused in the structure. To find out the load rating, engineers must be aware of the materials used, their physical properties, sizes of the components used, and the expected loads based on the traffic flow and AASHTO standards.

Load rating analysis can be done in several diverse ways including FEM analysis, and physical testing etc. These analysis techniques are used to identify the points of high dependency and where failure is most likely to occur. Using this data, a load rating is defined for the bridge which is conventionally expressed as a percentage of the maximum live load allowed.
Various codes and standards have been developed for load rating of bridges which include:

- LRFD Bridge Design Specifications
- AASHTO Guide Manual for Bridge Evaluation
- National Bridge Inspection Standards

These codes provide detailed guidance on how to properly load rate bridges and are widely used by bridge engineers and designers all over the world.

The routine practice of load rating the bridges is imperative to identify any faults and rectify them before they cause a major problem/failure. The weather/ environmental effects also must be taken into consideration while load rating bridges as they may have a significant impact on the stresses and strains endured by the structure.

In the recent times, load ratings can be calculated using remote sensing, NDTs and laser scanning/photogrammetry techniques are used to influence load rating decisions because of their high precision and accuracy and the fact that they reduce time and effort.

Overall, the load rating of a bridge is an imperative aspect that makes sure a bridge is safe and serviceable. In addition to that a bridge can live up to the age it was designed for, even exceed its design life.

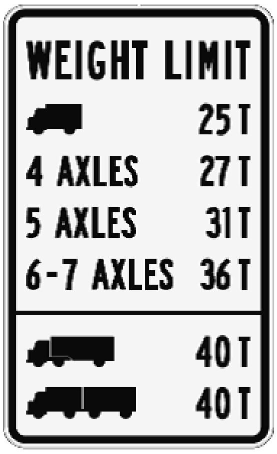


Figure 5 Example of load rating

Chapter 3

3. Methodology

3.1. General

This bridge monitoring system aims to reduce human effort and enhance the quality and efficiency of bridge inspection.

The process is initiated by a team of Engineers and technical operators who visit the site to gather the data using drone mounted cameras, sensors and performing nondestructive tests on the structure.

The data is then used to formulate 3D digital models and handed over to experienced structural engineers for visual inspection. Engineers then inspect the bridge at their desk and assign a soundness number to the bridge ranging from 1-5. This number will further indicate the level of the intricacy with which the specific bridge needs to be inspected if required. When many experienced bridge engineers review the data using the archived models, a better analysis will be completed, and problems will be given the correct rank.

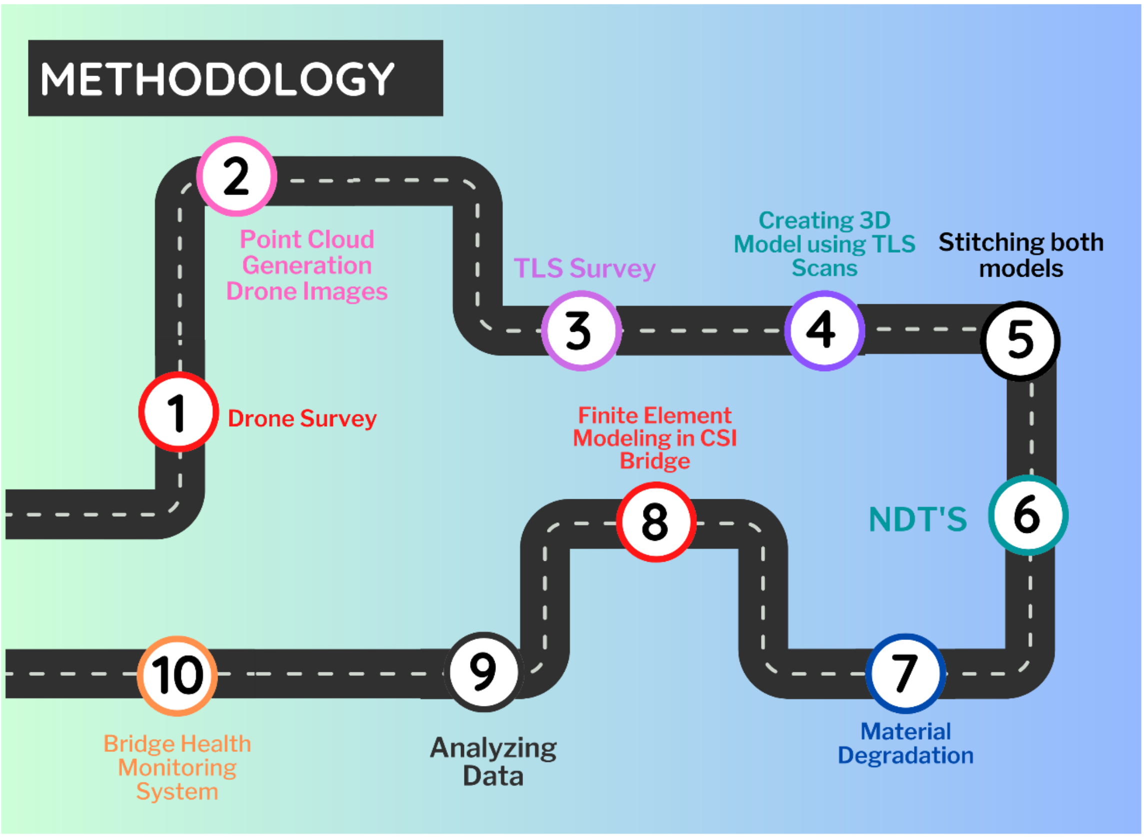


Figure 6 Step by Step Procedure

3.2. Site visit

The onsite practices include thorough drone flights to capture the sides, underbody, and top of the bridge along with topography and other minute details that might be crucial for bridge stability. The standard NDT's wherever possible and installation of accelerometers that will record the bridge deflection under normal traffic load.

This data will be compiled and analyzed where it can be studied and interpreted. Other important information such as visible deflections and exposed steel issues will also be highlighted via a checklist.

3.3. Develop Models

Once the data is obtained the photographs and point cloud data will be processed in the computers to formulate three dimensional models of the site and bridge. Using an AI based software to stitch all the points extracted from the photographs to form a point cloud model which can be used for the purpose of inspections. These models can then be archived for future references, also available to be cross examined by competent authorities whenever and wherever required.

3.4. NDT'S

Nondestructive tests are a very efficient tool in civil engineering for structural health monitoring, Schmidt hammers, rebar scanners and accelerometers can give a great deal of information to the user about the health of the structure. The Schmidt hammer and scanner data will be studied as and when required.

Accelerometers are a very effective tool to monitor bridges they can be planted in place at mid spans and supports to measure the deflections that the deck slab is going through to see whether it is within the permissible limit or not. If deflections are greater than what the bridge was designed for, it immediately needs to be rectified and retrofitted.

3.5. FEM Models

It is also referred to as simple finite element model, it does not compromise accuracy either. It is useful for not undertaking degree of freedom in redundant models that have very limited effect on the accuracy of the solutions found. The foremost thing that has resulted in limiting the degrees of freedom is that the time required for the mathematical calculations is significantly reduced. Due to this method many complex problems can be solved with ease and in time. In short it is said to optimize the design process without sacrificing accuracy of the problem.

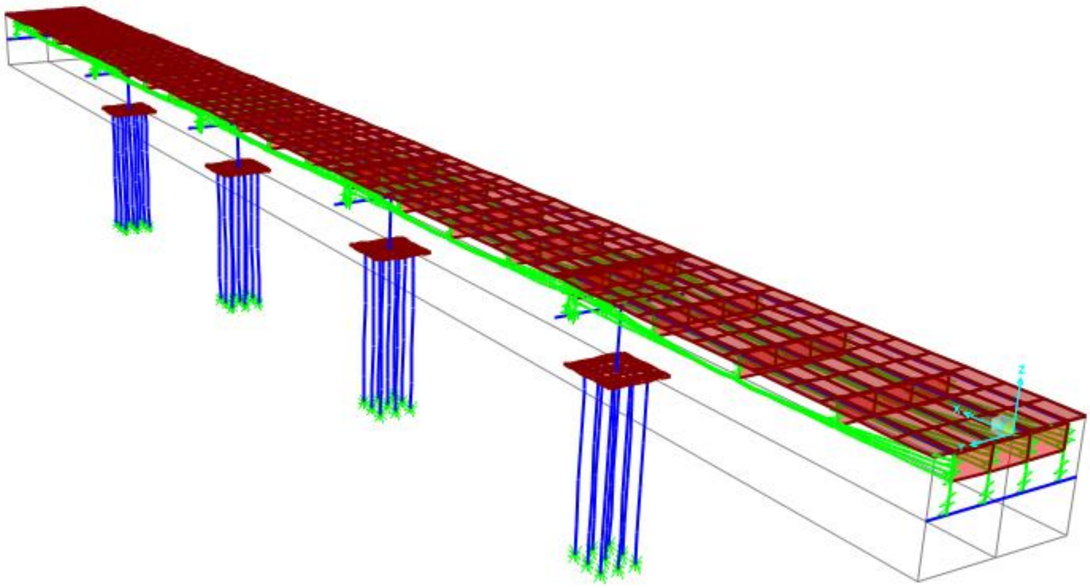


Figure 7 Fem model of design specs

An FEM model of the bridge will be created as per the dimensions and technical specifications given in the original drawings. All materials will be individually defined according to specification. The software utilized will be CSI Bridge. The software will run all the load combinations given by the AASHTO LRFD code for bridges specifically. The results will give the ultimate allowable capacity of the bridge and the implied demand required as per the given design loading.

Constructing an effective FEM model, considering multiple presence factors.[12]

3.6. Decreased FEM Model

All the values obtained from NDT testing are entered in CSI bridge model, and the values are compared with that of the designer. The values obtained are changed from the original model as the deterioration has occurred in the bridge due to natural calamity or aging effect. So that is the reason it is also called as decreased fem model. After the results have been attained a suitable idea is devised for making the standards of decreased fem model to reach at original FEM model. New Factor of safety are calculated by using flexure values as a reference.

3.7. Photogrammetry Model Creation

Photogrammetric models are created through state-of-the-art tools in the shape of drones that capture high quality images of the site including the superstructure and substructure. The photos are taken in an overlapping manner and then joined. This process helps in figuring out the real time dimensions and measurements of the object in question i.e., bridge.

The software uses artificial intelligence to stitch the overlapping (stereo) images using common points and formulates a 3D model. The quality of the model depends on the user's computational power and can give unbelievable accuracy. The software takes time to pick out points and identify different features on the ground including trees/shrubs, buildings etc., and assigns color codes to them. Then using artificial intelligence those recognized points and interpolated to make/register other points and a mesh is created using those points to give a final product.

The basic task of photogrammetry is to create a very accurate relationship between the images and the as-built structure at the time of imagery, hence the greater the density of the cloud the better the results will be. The model can then be used to find out features, such as visual defects and dimensions of different components of the bridge. [13]

Figure 8 Step 1: Photogrammetric point cloud.

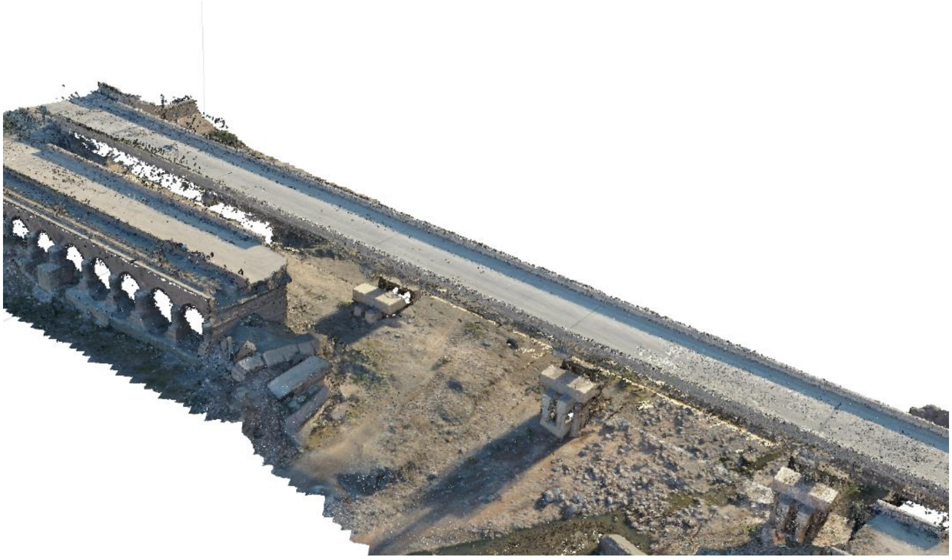


Figure 9 Step2: Dense cloud generation

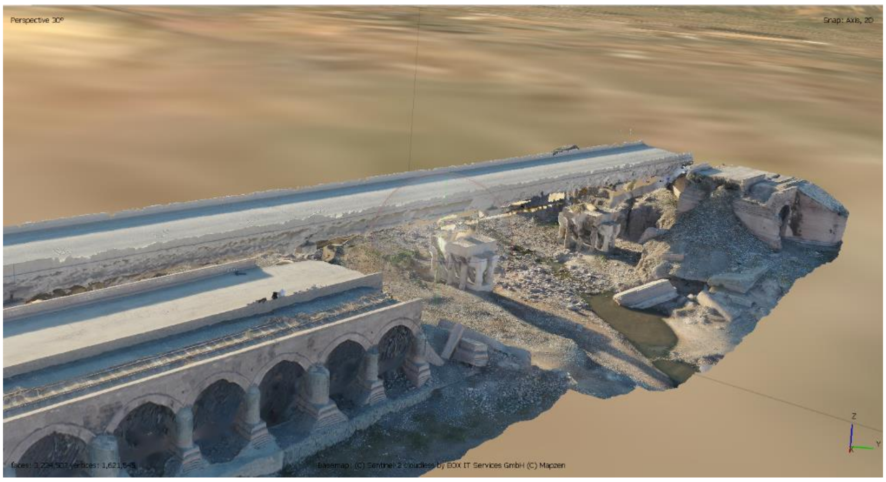


Figure 10 Step 3: Photogrammetric textured Model (AGI Meta shape)

3.8. Terrestrial Laser Scanner (TLS)

TLS works on a different phenomenon than photogrammetry, this technology directly picks up millions of points from the surrounding using a camera coupled with a LiDAR which increases accuracy of the point cloud to a great degree and then saves them into an SD card, which can then be plugged into the computer to extract and administer an AI based model construction.

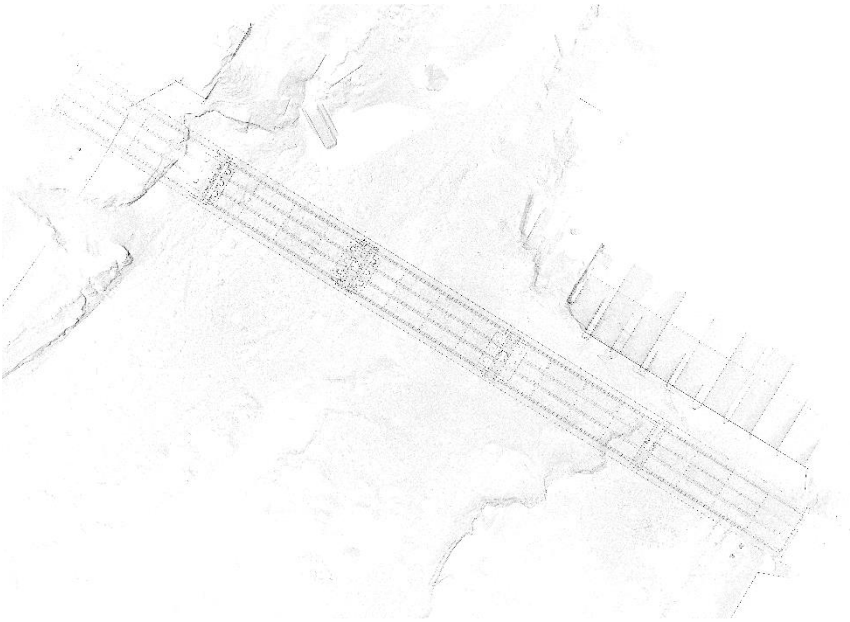


Figure 11 Terrestrial laser scanning output 1

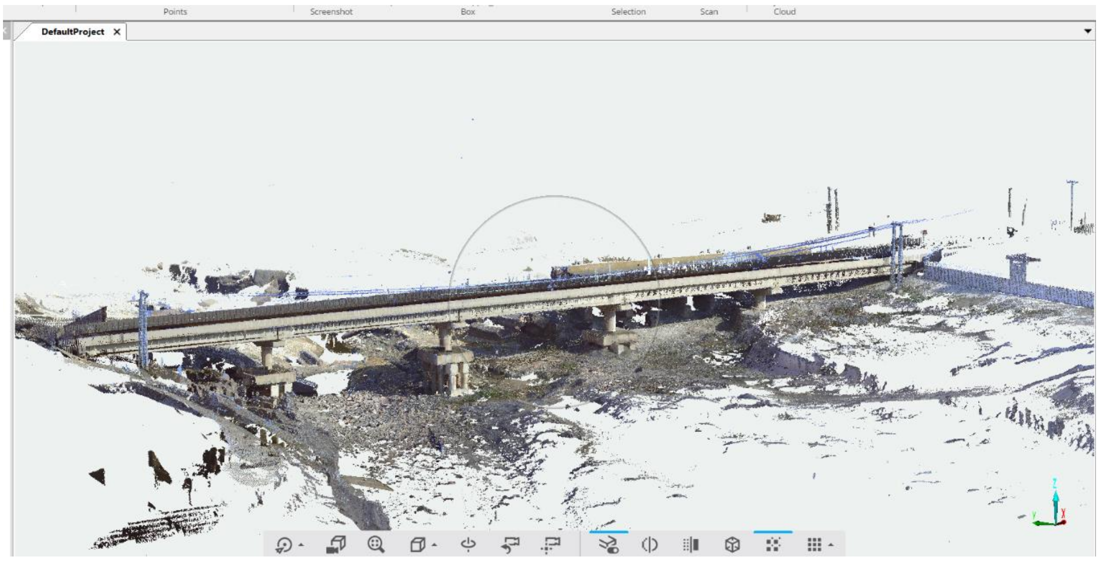


Figure 12 Terrestrial laser scan output 2

TLS uses special objects that need to be common in scans from different positions so that it can identify common points with a much higher accuracy as unlike photogrammetry it cannot identify the geographical/topographical features by itself.[14]

3.9. Mesh Generation

Mesh and dense clouds are an important aspect and outcome of different photogrammetry techniques and laser scanning. Dense clouds are formed by interpolating the points using AI so that a better/detailed depiction of the object's surface.

A mesh is formed from the dense point cloud. This is called surface reconstruction; this is done using trigonometry and the mesh is displayed as a juncture of several small triangles that connect the points in the dense cloud.

Although the dense cloud is more accurate than the mesh in terms of detail but a mesh is better for visualization of the surface as it is easily rendered and can be manipulated in 3D modelling software's. [15]

3.10. Bridge Evaluation System

To have an objective approach on the bridge evaluation and make uniform bridge inspections across the board a bridge management system is devised by our syndicate based on the concept initiated by AASHTO manual for bridge evaluation, which includes, segments for, data analysis, risk assessment, agency rules, cost benefit analysis, prioritization, and optimization.

The software includes the main components of bridge in accordance with their importance and the defects that can compromise a bridge's structural integrity with weights suggested, assumed and discussed by us attached to them. The bridge inspector must evaluate every defect out of 5 and then, the program will assign a soundness number 1-5 with one being the best and 5 being the worst. This soundness number will be the basis of how much and how urgent attention a certain bridge requires.

Chapter 4

4. Results and discussions (Case Study)

4.1. Background on site

Takhta Baig bridge is a 150m long 5 span bridge situated on the National Highway 5 at 1715+100 (Peshawar – Torkham Section). This bridge was originally built by the British using conventional methods, an arch system using the aqueduct concept introduced by the Romans. This was a 2-lane bridge for traffic and a railway line, which collapsed due to flooding. A new bridge was constructed using reinforced concrete, 5 spans 30m each covered a total length of 150m, the new bridge was again affected by the floods and soon the need for retrofitting arose. The bridge was repaired and put into service. In the recent monsoon floods, it was assumed that the bridge took some damage to itself and hence was considered one of the sites this project could be done on.

4.2. Reasons for Selection

- The bridge is located within a 100 km radius of the university.
- The bridge has a history of being damaged and repaired, so inspecting this bridge will add more value to the project.
- The original drawings of this bridge were procured easily through the design office of NHA.
- The riverbed was dry and easily accessible on foot, which gave way to the use of the already available TLS device and not a drone mounted laser scanner which would have incurred costs way above the budget of this project.

4.3. Visual inspection

As a matter of fact, it is stated that two parallel bridges were to be seen. The antique bridge was not serviceable anymore and a new bridge was to be seen that was partially deteriorated and retrofitted. The inspection work commenced immediately, and the team was divided into two major groups to simultaneously do TLS and drone surveys.

4.3.1. TLS employed inspection.

TLS was used for the substructure's survey as drone was incapable of capturing the underbody due to unavailability of a top mounted camera/scanner, while the drone was employed for aerial (top and side views) of the bridge.

Figure 13 Snap of model obtained through TLS.

4.3.2. Drone employed inspection.

An unmanned aerial vehicle (UAV) was necessary to inspect the areas that were dangerous or difficult to access manually. UAV flight was administered from a base point on the bridge. The drone path was demarcated on the flight application (Drone Deploy) and the device was sent to capture HD stereo images of the bridge.

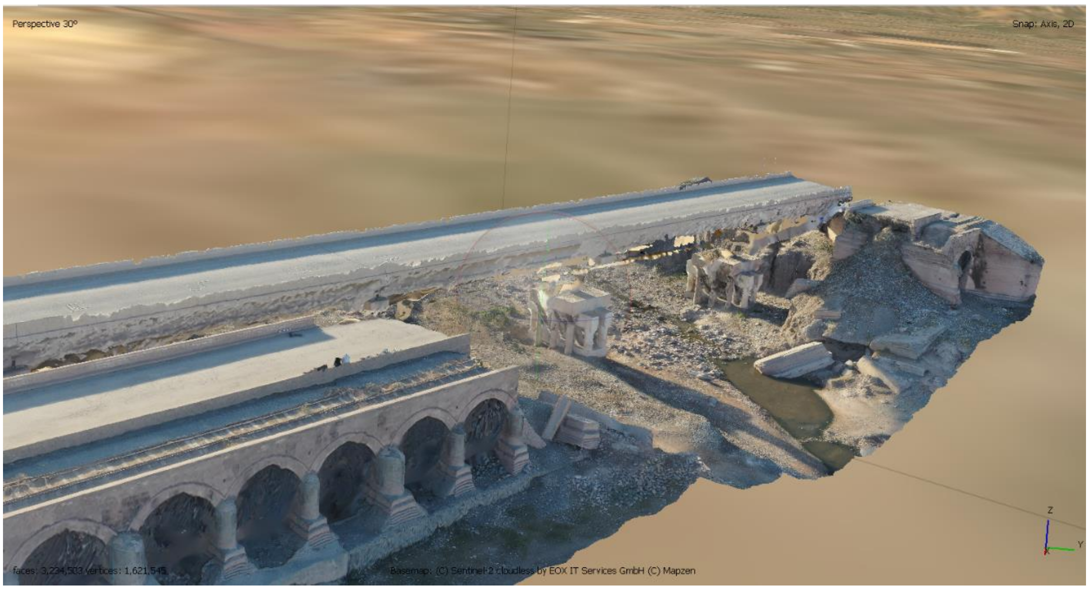


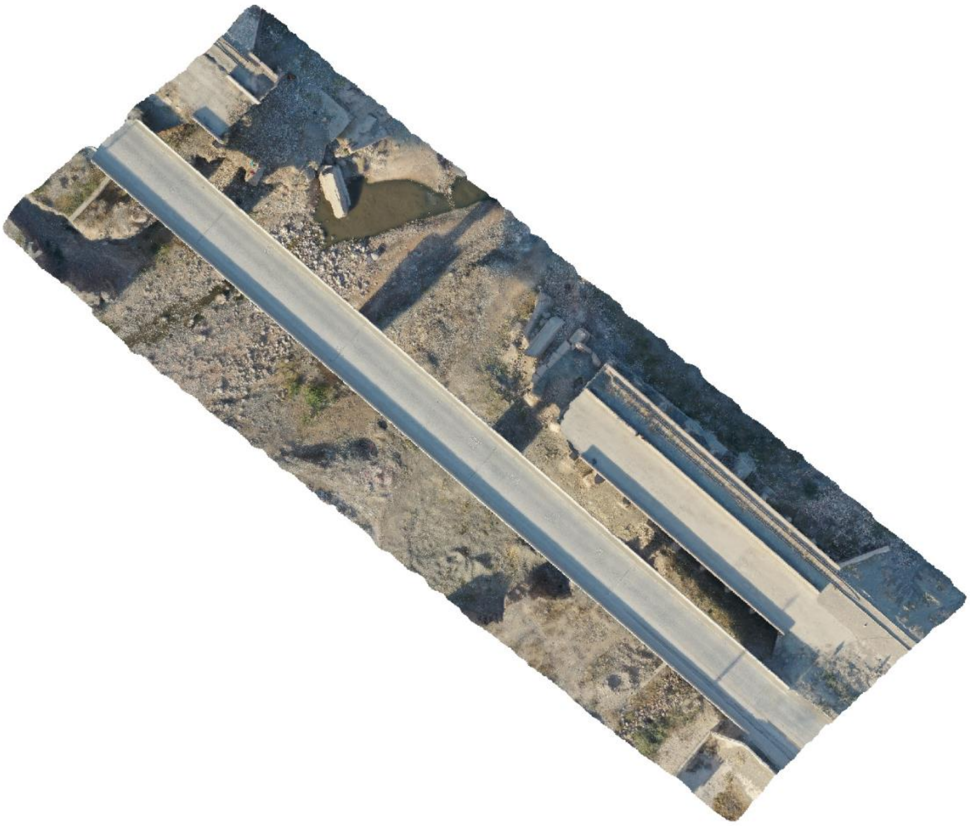
Figure 14 Snap of model obtained through drone survey.

4.3.3. Photogrammetry Specifications Report

Agisoft Metashape

Processing Report

12 May 2023



Survey Data

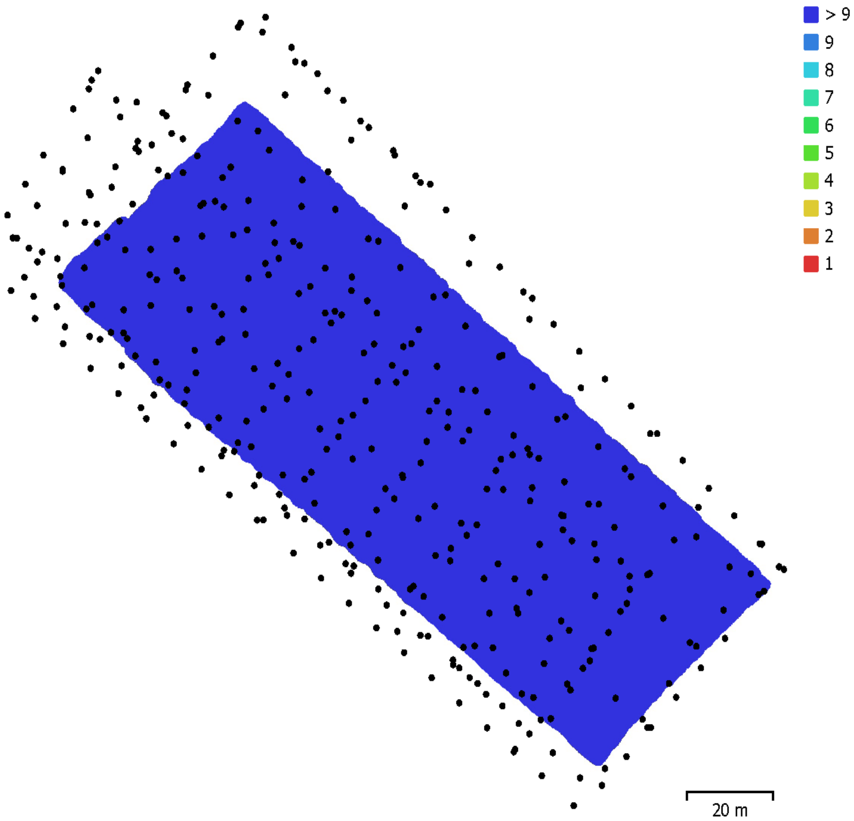


Fig. 1. Camera locations and image overlap.

Number of images:	395	Camera stations:	382
Flying altitude:	77.6 m	Tie points:	2,243,378
Ground resolution:	1.7 cm/pix	Projections:	9,281,459
Coverage area:	9.25e+03 m²	Reprojection error:	1.26 pix

Camera Model	Resolution	Focal Length	Pixel Size	Precalibrated
Test_Pro (10.26mm)	5472 x 3648	10.26 mm	2.41 x 2.41 μm	No

Table 1. Cameras.

Camera Calibration

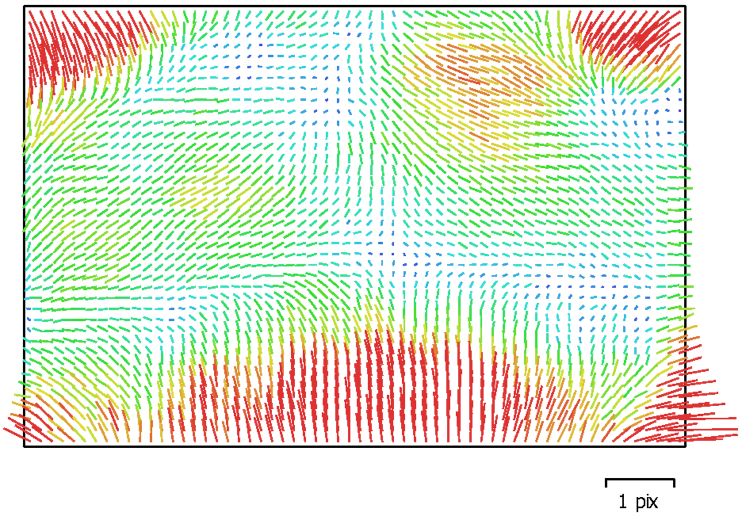


Fig. 2. Image residuals for Test_Pro (10.26mm).

Test_Pro (10.26mm)
395 images

Type	Resolution	Focal Length	Pixel Size
Frame	**5472 x 3648**	**10.26 mm**	**2.41 x 2.41 µm**

	Value	Error	F	Cx	Cy	K1	K2	K3	P1	P2
F	**4296.79**	0.02	1.00	-0.04	-0.62	-0.24	0.25	-0.22	0.00	-0.21
Cx	**-2.73786**	0.019		1.00	0.02	-0.02	0.01	-0.01	0.92	-0.00
Cy	**-61.355**	0.019			1.00	-0.08	0.02	-0.01	0.00	0.70
K1	**0.00897581**	2e-05				1.00	-0.96	0.90	-0.03	-0.10
K2	**-0.011749**	7.6e-05					1.00	-0.98	0.01	0.03
K3	**0.0102898**	8.9e-05						1.00	-0.01	-0.02
P1	**0.000247454**	1.5e-06							1.00	0.00
P2	**-0.00295569**	1.3e-06								1.00

Table 2. Calibration coefficients and correlation matrix.

Camera Locations

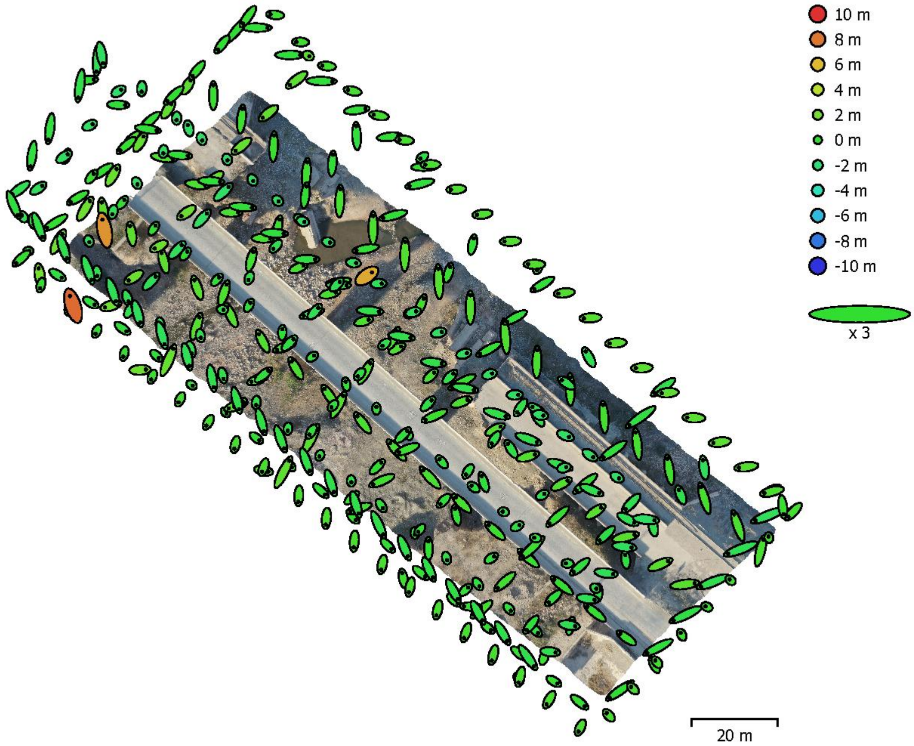


Fig. 3. Camera locations and error estimates.
Z error is represented by ellipse color. X,Y errors are represented by ellipse shape.
Estimated camera locations are marked with a black dot.

X error (m)	Y error (m)	Z error (m)	XY error (m)	Total error (m)
0.759509	0.818711	1.0492	1.11675	1.53231

Table 3. Average camera location error.
X - Longitude, Y - Latitude, Z - Altitude.

Digital Elevation Model

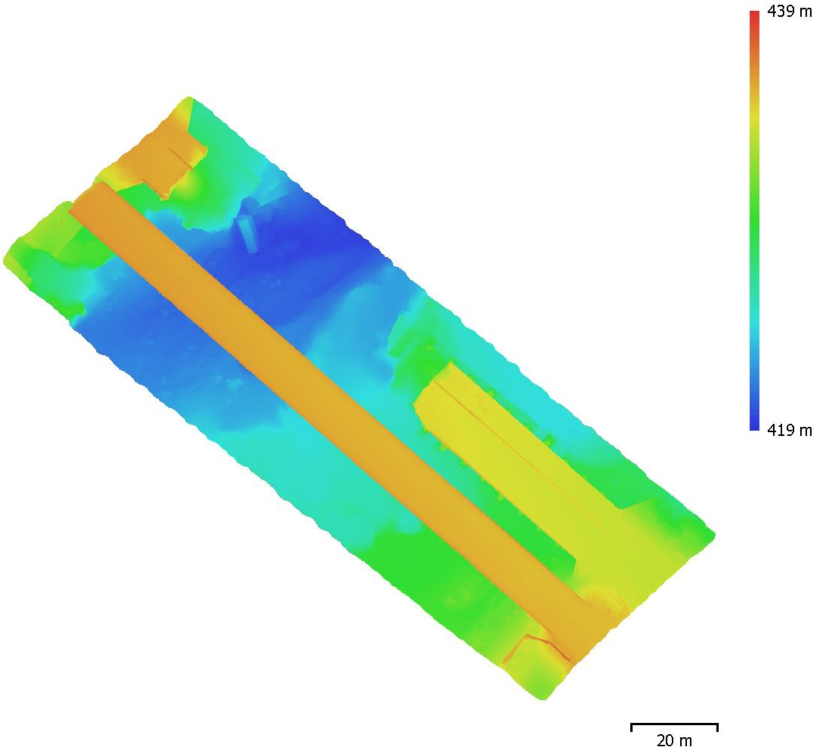


Fig. 4. Reconstructed digital elevation model.

Resolution:	3.41 cm/pix
Point density:	860 points/m²

Processing Parameters

General	
Cameras	395
Aligned cameras	382
Coordinate system	WGS 84 (EPSG::4326)
Rotation angles	Yaw, Pitch, Roll
Point Cloud	
Points	2,243,378 of 3,961,805
RMS reprojection error	0.603585 (1.25915 pix)
Max reprojection error	2.04544 (61.0684 pix)
Mean key point size	1.92732 pix
Point colors	3 bands, uint8
Key points	No
Average tie point multiplicity	6.19551
Alignment parameters	
Accuracy	Highest
Generic preselection	Yes
Reference preselection	Source
Key point limit	300,000
Key point limit per Mpx	1,000
Tie point limit	60,000
Exclude stationary tie points	Yes
Guided image matching	No
Adaptive camera model fitting	No
Matching time	5 hours 26 minutes
Matching memory usage	3.44 GB
Alignment time	55 minutes 11 seconds
Alignment memory usage	2.57 GB
Date created	2023:01:07 00:33:16
Software version	1.7.6.13524
File size	437.27 MB
Depth Maps	
Count	382
Depth maps generation parameters	
Quality	High
Filtering mode	Mild
Max neighbors	40
Processing time	10 hours 56 minutes
Memory usage	12.26 GB
Date created	2023:01:08 18:08:27
Software version	1.7.6.13524
File size	2.91 GB
Dense Point Cloud	
Points	16,172,521
Point colors	3 bands, uint8
Depth maps generation parameters	
Quality	High
Filtering mode	Mild
Max neighbors	40
Processing time	10 hours 56 minutes
Memory usage	12.26 GB

Dense cloud generation parameters	
Processing time	4 hours 27 minutes
Memory usage	12.20 GB
Date created	2023:01:08 22:35:40
Software version	1.7.6.13524
File size	1.26 GB
Model	
Faces	3,234,503
Vertices	1,621,545
Vertex colors	3 bands, uint8
Texture	4,096 x 4,096, 4 bands, uint8
Depth maps generation parameters	
Quality	High
Filtering mode	Mild
Max neighbors	40
Processing time	10 hours 56 minutes
Memory usage	12.26 GB
Reconstruction parameters	
Surface type	Arbitrary
Source data	Dense cloud
Interpolation	Enabled
Strict volumetric masks	No
Processing time	7 minutes 10 seconds
Memory usage	7.59 GB
Texturing parameters	
Mapping mode	Generic
Blending mode	Mosaic
Texture size	4,096
Enable hole filling	Yes
Enable ghosting filter	Yes
UV mapping time	1 minutes 53 seconds
UV mapping memory usage	2.25 GB
Blending time	3 minutes 48 seconds
Blending memory usage	2.22 GB
Blending GPU memory usage	1.28 GB
Date created	2023:01:09 13:23:45
Software version	1.7.6.13524
File size	167.48 MB
System	
Software name	Agisoft Metashape Professional
Software version	1.7.6 build 13524
OS	Windows 64 bit
RAM	15.77 GB
CPU	Intel(R) Core(TM) i7-1065G7 CPU @ 1.30GHz
GPU(s)	NVIDIA GeForce MX230

4.3.4. Stitched Model

The model created using the drone would be then converted to point cloud and stitched together with the TLS scan using Auto Desk Recap to get a more accurate and comprehensive representation of the bridge. And further imported into a Revit file.

4.3.5. Advanced Visual Representation

A Revit model has been made from the drawings/specifications available and the cracks and defects observed during visual inspection of the bridge were incorporated in the Revit model of the bridge.

This Revit model is then used to get employed into the VR headset.

The main advantage of VR headset is that it gives a virtual representation of the structure, and it can allow the user to have a walk through via a headset.

Our bridge condition can be seen and observed with the VR headset without visiting the site with the help of the VR headset.

This is just a representation of what can be done and achieved with the VR headset. We have used Oculus Go due to financial shortage. If advanced models such as Oculus Quest rift or Oculus Quest are used it can be utilized to view scanned point cloud of the bridge using Faro scene Software. [16]

Registration report screenshots are attached below.

Registration Report

Project	Takhta baig
Cluster	Scans
Recording Period	1/1/2002, 12:13:42 AM - 1/1/2002, 2:34:57 AM
Location	
Report Date	5/24/2023, 6:10:00 PM

Color Coding

Point Error	< 8 mm	> 20 mm
Overlap	> 25.0 %	< 10.0 %

Figure 15 Registration Report pt1

Overview

Scan Point Statistics

Maximum Point Error	14.8 mm
Mean Point Error	6.5 mm
Minimum Overlap	6.2 %

Figure 16 Registration Report pt2

Scan Errors

Scan Point Statistics

Cluster/Scan	Connections	Max. Point Error [mm]	Mean Point Error [mm]	Min. Overlap
MCE_OM033	3	5.5	4.6	15.2 %
MCE_OM042	4	10.1	5.3	14.0 %
MCE_OM034	6	14.8	8.0	22.8 %
MCE_OM037	7	8.5	5.9	8.8 %
MCE_OM036	7	10.1	6.4	6.2 %
MCE_OM038	7	10.7	6.8	14.5 %
MCE_OM039	7	9.6	5.5	14.0 %
MCE_OM040	3	10.7	7.0	14.5 %
MCE_OM041	6	14.8	8.6	6.2 %

Figure 17 Registration report pt3

Detailed Errors

Scan Point Statistics

Cluster/Scan 1	Cluster/Scan 2	Point Error [mm]	Overlap
MCE_OM042	MCE_OM039	2.8	14.0 %
MCE_OM042	MCE_OM037	2.1	34.8 %
MCE_OM042	MCE_OM036	10.1	19.1 %
MCE_OM042	MCE_OM038	6.3	20.8 %
MCE_OM034	MCE_OM033	3.4	57.9 %
MCE_OM034	MCE_OM038	8.8	53.8 %
MCE_OM034	MCE_OM036	4.6	34.9 %
MCE_OM034	MCE_OM037	6.7	24.5 %
MCE_OM034	MCE_OM041	14.8	30.1 %
MCE_OM034	MCE_OM039	9.6	22.8 %
MCE_OM037	MCE_OM033	5.5	22.6 %
MCE_OM037	MCE_OM036	3.4	50.9 %
MCE_OM036	MCE_OM033	4.9	15.2 %
MCE_OM038	MCE_OM037	7.3	35.2 %
MCE_OM038	MCE_OM036	5.0	49.4 %
MCE_OM038	MCE_OM041	6.6	36.4 %
MCE_OM039	MCE_OM037	7.7	18.3 %
MCE_OM039	MCE_OM036	7.4	18.2 %
MCE_OM039	MCE_OM038	3.1	43.5 %
MCE_OM039	MCE_OM041	5.1	17.5 %
MCE_OM040	MCE_OM038	10.7	14.5 %
MCE_OM040	MCE_OM039	2.6	18.1 %
MCE_OM040	MCE_OM041	7.7	54.0 %
MCE_OM041	MCE_OM037	8.5	8.8 %
MCE_OM041	MCE_OM036	9.2	6.2 %

Figure 18 Registration Report pt 4

Inclinometer Mismatches

Cluster/Scan	Scan	Mismatch [deg]
MCE_OM042	MCE_OM042	0.0347
MCE_OM034	MCE_OM034	0.0472
MCE_OM040	MCE_OM040	0.0109
MCE_OM039	MCE_OM039	0.0195
MCE_OM038	MCE_OM038	0.0252
MCE_OM041	MCE_OM041	0.0428
MCE_OM037	MCE_OM037	0.0282
MCE_OM036	MCE_OM036	0.0386
MCE_OM033	MCE_OM033	0.0167

Figure 19 Registration report pt5

4.3.6. NDT's

Nondestructive tests were carried out on the bridge as far as human reach was concerned. Schmidt hammer and accelerometers were used to estimate the compressive strengths and deflections occurring on the bridge. During the inspection the compressive strength of various components of the bridge were necessary to be known. The best available NDT device to us was a Schmidt hammer, the values of compressive strengths were determined from the following components. Results are tabulated below.[3]

	Interior First Girder					
	Horizontal	Vertical	Horizontal	Abutment	Horizontal Diaphragm	Deck
Readings	50	50	29	44	32	39
	44	32	43	37	33	48
	44	48	42	36	28	42
	44.5	51	42	16	28	43
	44	48	41	44	25	38
	48	49	40	29	39	45
	42	48	40	34	30	33
	46	47	37	28	30	45
	47	49	38	32	27	45
	42	52	45	38	33	42
	39	52	37	44	35	43
	42	53	47	29	32	39
	46	53	43	33	36	42
	47	55	43	34	28	41
	42	53	39	35	29	38
	45	60	41	35	31	39
Average	**44.53125**	**50**	**40.4375**	**34.25**	**31**	**41.375**
Graph Reading (N/mm2)	**43.5**	**43**	**36**	**27**	**21**	**36**
Compressive strength Psi	**6309.142**	**6236.62**	**5221.36**	**3916.02**	**3045.79**	**5221.36**

Figure 20 Compressive Strengths using Schmidt Hammer.

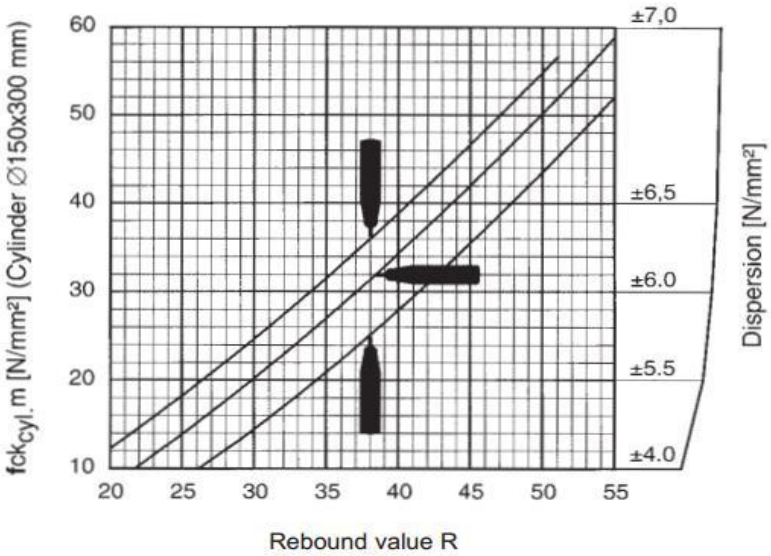


Figure 21 Rebound Values relation with compressive strength.

Accelerations, vibrations and substructural movements on either bridge deck, or girder were to be monitored. However due to unforeseen circumstances the accelerometer readings were not attained. Nonetheless accelerations were measured on a separate bridge inspected by a third party and accelerometer data was imported for similar 25m span and then deflections were calculated, by digitizing the acceleration time graphs and using a MATLAB code to double integrate the values and formulate a displacement time graph.

MATLAB code is mentioned below:

```
%%accelerations are integrated twice to produce displacements

clear all

close all

clc

time = [          1.66084,    1.71559,    1.74601,    1.79468,
 1.84943,    1.8981,     1.94677,    2.00152,    2.05019,
 2.10494,    2.16578,    2.20836,    2.23878,    2.2692,
 2.31787,    2.38479,    2.42738,    2.46996,    2.53688,
 2.57338,    2.61597,    2.67072,    2.73764,    2.77414,
 2.84715,    2.91407,    2.9384,     2.98099,    3.00532,
 3.05399,    3.12091,    3.16958,    3.22433,    3.27909,
 3.32167,    3.37643,    3.41901,    3.47376,    3.54068,
 3.58935,    3.62586,    3.72319,    3.75361,    3.82662,
 3.86312,    3.91179,    3.93612,    3.98479,    4.03346,
 4.0943,     4.13688,    4.18555,    4.22814,    4.28289,
 4.31331,    4.37414,    4.41673,    4.47148,    4.52015,
 4.5749,     4.62966,    4.69049,    4.73916,    4.78783,
 4.84867,    4.90342,    4.95209,    4.99468,    5.04943,
```

```
5.11027,    5.1711,     5.22586,    5.26844,    5.31711,
5.38403,    5.43878,    5.49354,    5.54829,    5.60304,
5.65779,    5.71863,    5.77338,    5.83422,    5.87072,
5.91939,    5.97414,    6.02281,    6.0654,     6.09582,
6.16882,    6.22966,    6.30875,    6.3635,     6.41217,
6.49125,    6.53384,    6.60076,    6.6616,     6.7346,
6.79544,    6.84411,    6.89886,    6.94753,    7.00837,
7.07528,    7.11787,    7.19696,    7.25779,    7.34297];


acc = [      -0.00181818, 0.00644628, -0.00975207, 0.0203306,   -
0.0312397,   0.0305785,   -0.0305785,  0.0269421,   -0.026281,
0.0302479,   -0.0312397,  0.0418182,   -0.0130579,  -0.00214876, -
0.0299174,   0.0335537,   -0.0418182,  0.0461157,   -0.0444628,  0.02,
-0.0233058,  0.0438017,   -0.0712397,  0.0642975,   -0.0765289,
0.0894215,   -0.0282645,  -0.0031405,  -0.0745455,  0.0636364,   -
0.0603306,   0.0695868,   -0.0652893,  0.045124,    -0.0166942,
0.0176859,   -0.0193388,  0.00942149,  -0.0147107,  0.0193388,   -
0.0110744,   0.0147107,   -0.0061157,  0.00545455,  -0.00809917,
0.0031405,   0.000495868,      0.00181818,  -0.00909091, 0.00743802,
-0.00942149, 0.00842975,  -0.0127273,  0.0150413,   -0.00842975,
0.0143802,   -0.0127273,  0.0120661,   -0.0123967,  0.0150413,   -
0.0166942,   0.0117355,   -0.0123967,  0.0117355,   -0.00842975,
0.00909091,  -0.0100826,  0.00710744,  -0.00743802, 0.0120661,   -
0.0150413,   0.011405,    -0.0133884,  0.0150413,   -0.0170248,
0.0229752,   -0.0173554,  0.0213223,   -0.0196694,  0.0147107,   -
0.0133884,   0.00809917,  -0.00413223, 0.00380165,  -0.00115702,
0.00214876,  -0.00214876, 0.00413223,  -0.0031405,  0.00710744,  -
0.00280992,  0.00446281,  -0.00710744, 0.00545455,  -0.00876033,
0.00710744,  -0.00710744, 0.00842975,  -0.00644628, 0.0107438,   -
0.0077686,   0.0104132,   -0.0100826,  0.00479339,  -0.00743802,
0.00247934,  -0.00380165, 0.00280992,  -0.00115702];


figure
plot(time,acc)
xlabel('Time (sec)')
ylabel('Acceleration (mm/sec^2)')
%%Design High Pass Filter
fs = 8000; % Sampling Rate
fc = 0.1/30;  % Cut off Frequency
order = 6; % 6th Order Filter
%%Filter  Acceleration Signals
[b1 a1] = butter(order,fc,'high');
accf=filtfilt(b1,a1,acc);
```

```
figure (2)
plot(time,accf,'r'); hold on
plot(time,acc)
xlabel('Time (sec)')
ylabel('Acceleration (mm/sec^2)')
%%First Integration (Acceleration - Veloicty)
velocity=cumtrapz(time,accf);
figure (3)
plot(time,velocity)
xlabel('Time (sec)')
ylabel('Velocity (mm/sec)')
%%Filter  Veloicty Signals
[b2 a2] = butter(order,fc,'high');
velf = filtfilt(b2,a2,velocity);
%%Second Integration   (Velocity - Displacement)
Displacement=cumtrapz(time, velf);
figure(4)
plot(time,Displacement)
xlabel('Time (sec)')
ylabel('Displacement (mm)')
```

The graph of accelerations is attached below.

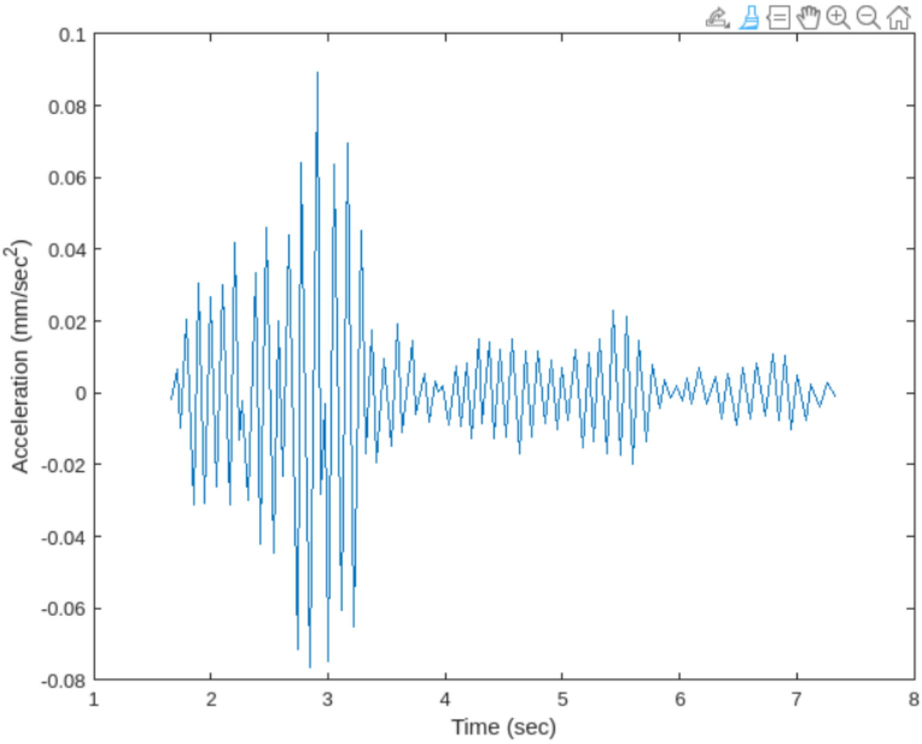


Figure 22 Accelerations of a similar bridge under HL93 LL

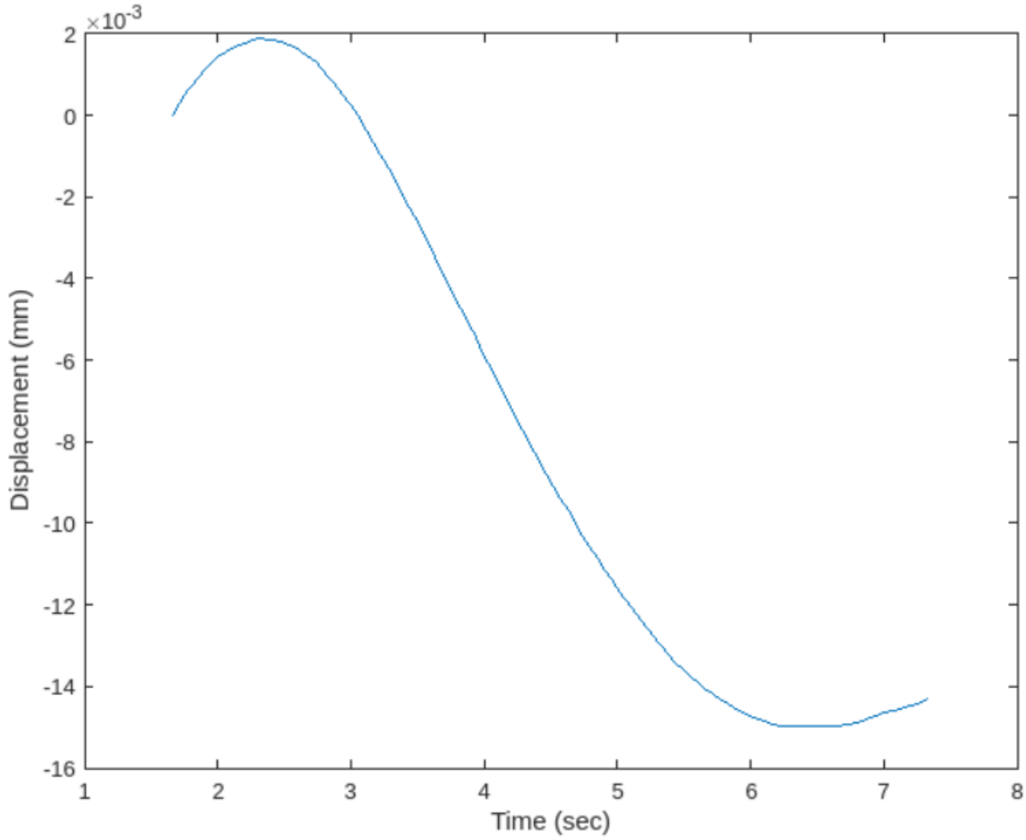


Figure 23 Displacement/Deflections obtained from acceleration.

These acceleration and deflection values were compared to that of our FEM model in CSI bridge and these were found to be comparable for the same age, as both bridges were 20 years old. Attached below are the deflections for our model of the bridge at 20-year degradation factor and these are comparable to that obtained above. Deflection recorded are -16mm maximum for 30m span and -15mm for a 30m span bridge (case study). Hence the bridge is deemed serviceable.

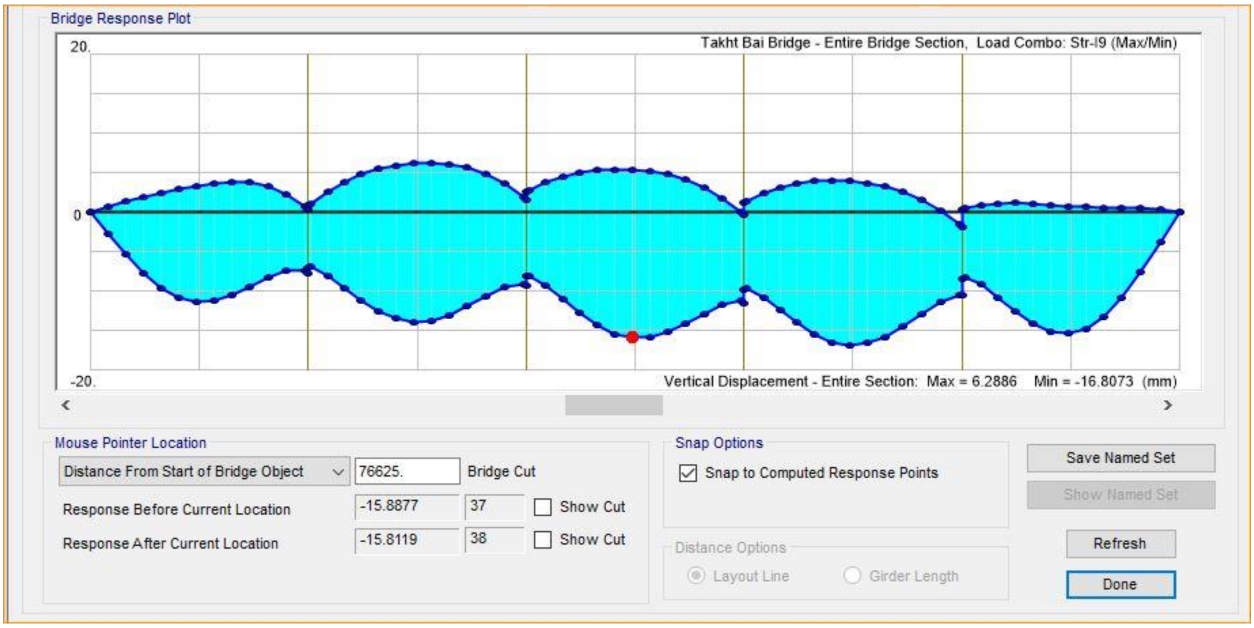


Figure 24 FEM Model Displacements

4.4. Reduced Strength FEM Model

Finite element of the bridge's original design specification is created on CSI bridge beforehand and then after the inspection and evaluation another FEM is created on decreased specifications also referred as reduced FEM, the specifications will be reduced as shown below. Other reductions may be made as deemed necessary by the evaluator based on visual criteria.

Material	Deterioration Criteria
Steel / Rebar	The diameter is reduced 0.034798 mm every year. [1]

Below shows the charts of how the factor of safety has decreased over time, due to corrosion of the rebars over specific periods of time using the empirical formula mentioned above.

Figure 25 FOS Interior Girder 1 over 80 years

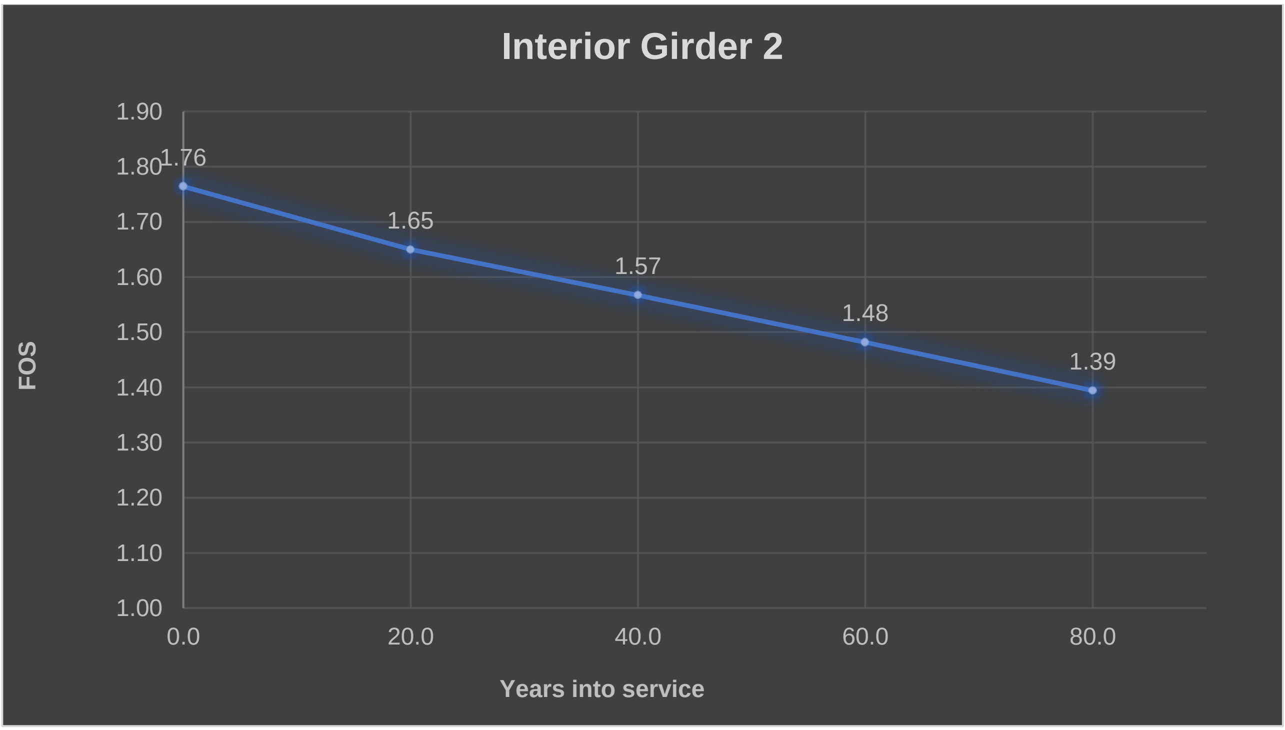


Figure 26 FOS Interior Girder 2 over 80 years

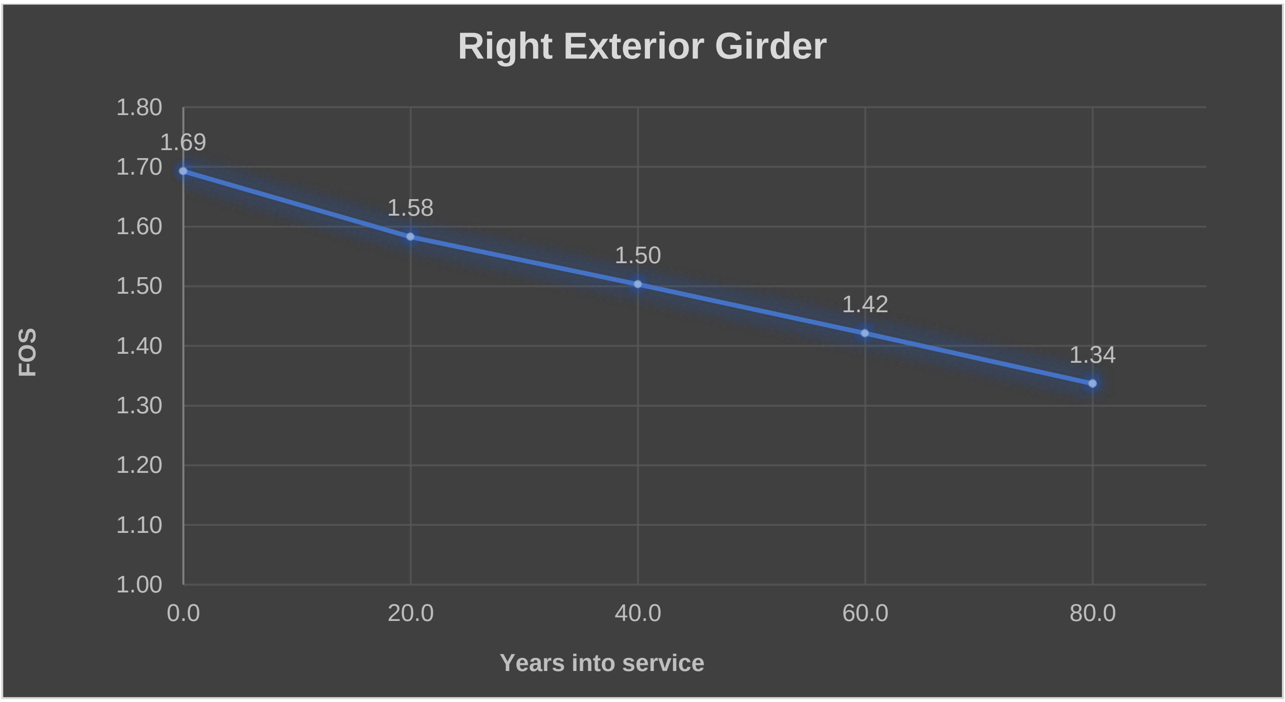


Figure 27 FOS Right Exterior Girder over 80 years

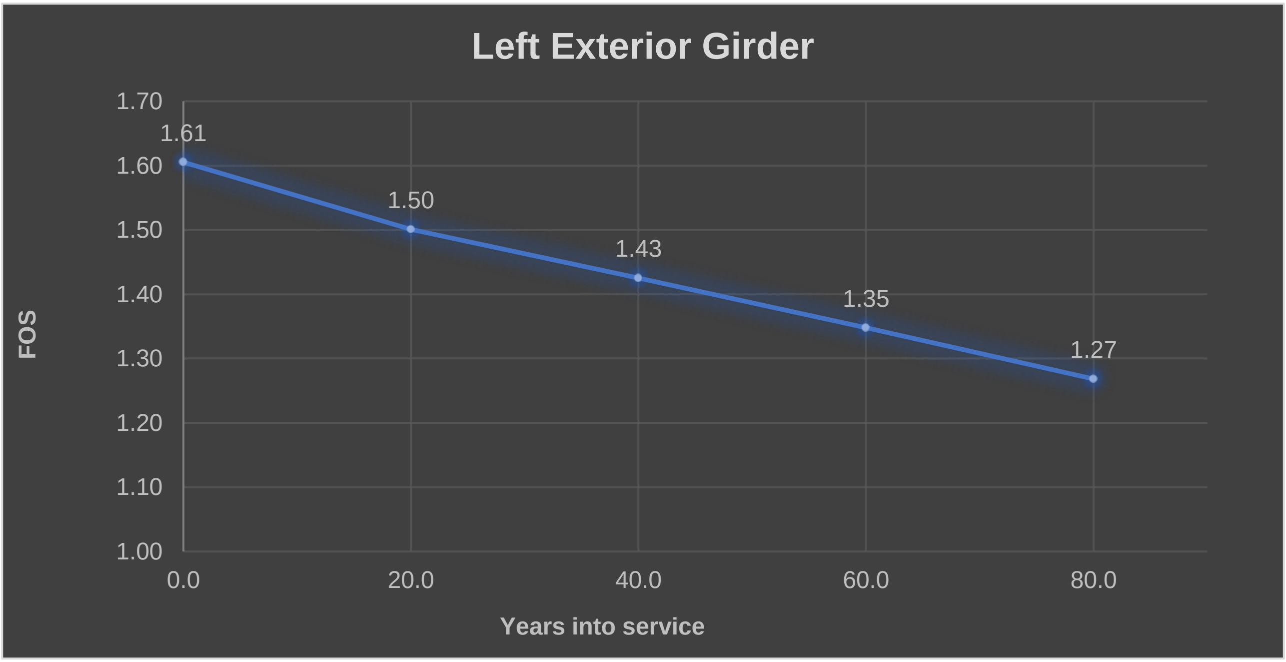


Figure 28 FOS Left Exterior Girder over 80 years.

4.5. MCE Bridge Health Monitoring System

Special software has been developed that will assign a soundness number to the bridge based on the defects of the bridge evaluated by the examiner. The software takes into consideration the defects that structurally harm the bridge, namely, spalling, delamination, shrinkage etc. on the integral components i.e., Pier, Pile, girder, deck, transoms.

The skilled bridge engineer is expected to assign each defect a number from 1-5 based on the condition of a certain defect present on the bridge on consultation with the archived models and after a series of calculations based on weighted averages will assign a soundness number to the bridge. The number will be from 1-5 with 1 being the best and 5 the worst. The evaluator will know how immediately the bridge needs attention.

4.5.1. Weightages assigned.

The weightages assigned are as per the following values, the Bridges individual Components with their weightages are:

Component	Weightage
Girder	30%
Pier	25%
Transom	20%
Piles	15%
Deck Slab	10%

Figure 29 Component Weightages

The induvial components will be evaluated on the following defects:

Defect	Weightage
Spalling	30%
Plastic Shrinkage Cracks	20%
Corrosion	25%
ASR & Carbonation	25%

Figure 30 Defects Weightages

All the values obtained will be rounded up to a specific number.

Soundness Number	Quality	Action	Inspection Timeline
1	Very Good	No repairs	5 Years
2	Good	Localized repairs	3 Years
3	Satisfactory	Global Retrofitting	1 Years
4	Poor	Global/Local Retrofitting	6 Months
5	Very Poor	Global/Local - Urgent Retrofitting	6 Months

Figure 31 Soundness Number 1-5

4.5.2. <u>Interface of the application</u>

The interface is as follows:

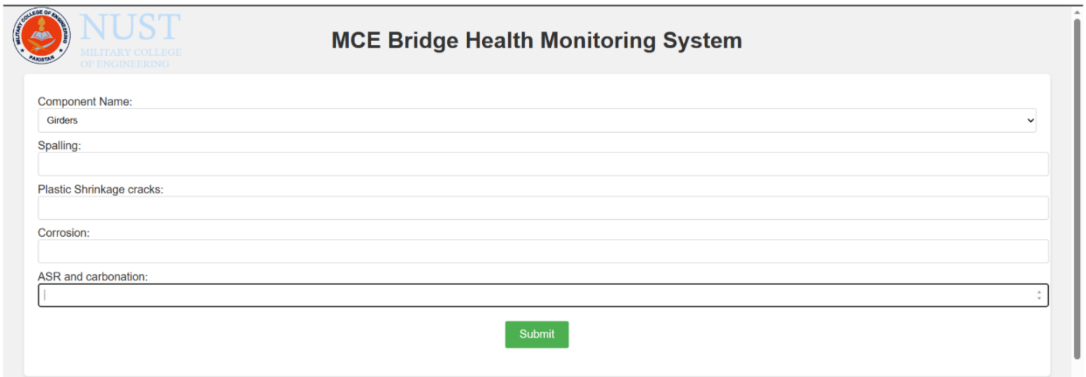


Figure 32 Bridge Assessment App Snapshot 1

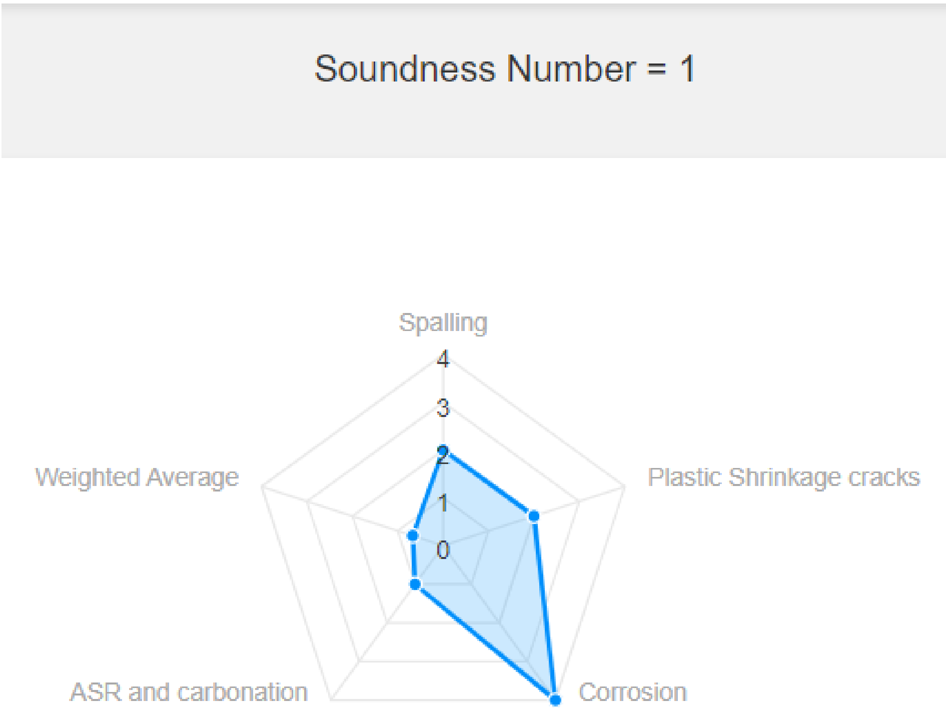


Figure 33 Bridge Assessment App Snapshot 2

Chapter 5

5. Conclusion

5.1. Recommendations

The fact of the matter is that there is always room for improvement. Even though limited resources were available to us, yet we still managed to extract the best out of it and make it worthwhile. However, if all the resources required were at our disposal, the findings would have been better understood and explained. To execute this on ground, the following enhancements are advisable.

5.2. Thermal Imaging Sensor

One main aspect that was missing in our project was thermal imaging sensor due to its unavailability. Thermal Imaging is a very crucial process in determining the defects, it is suggested to be the first step in Bridge health management systems. It would have been mainly used in following prospects:

- It creates image by temperature variations also referred as thermograph.
- Creates a complete thermal signature emitted by the bridge.
- It is used for finding hidden moisture content in structural elements of the bridge for example bridge deck or support structures.
- Voids generated in the bridge that are not visible to naked eye can be detected in thermograph due to temperature anomalies present in it which would be detected by the site inspector by viewing the results attained from thermal imaging camera.

This instrument is not solely responsible for detecting the defects, but it gives a go head to the bridge inspector for conducting various tests on bridge depending upon the data obtained from thermographs.[17]

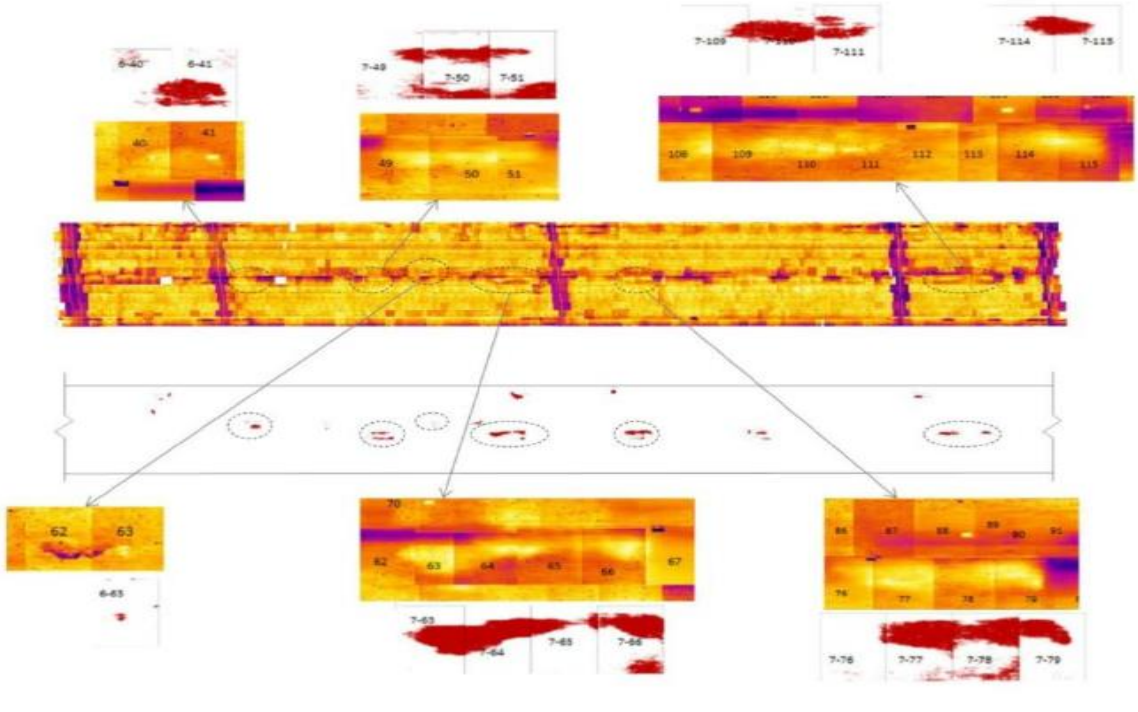


Figure 34 Depiction of delamination via thermograph.

5.3. Drone

UAV (unmanned aerial vehicle) used in our case study had a major limitation of the 360-degree camera and/or a laser scanner installed on it, due to which we were unable to capture structural elements of the bridge present below deck such as in between girders. Due to unavailability of this type of drone, it costed us a lot of time, and use of TLS (terrestrial laser scanner) was required for analysing the structural elements present at the bottom of the bridge that resulted in both cost and time. The use of TLS was only applicable in our case as it was a dry bed in the given case. Furthermore, help of an additional software i.e., Autodesk Recap was employed to stitch the point clouds attained from drone and TLS survey.

5.4. Schmidt Hammer Test

SCHIMDT hammer test was used to measure compressive strength of concrete. But as easy as it is to use, it has certain short comings. This instrument is surface sensitive which means that it will affect the values for compressive strengths of concrete if different variations occur in it such as moisture content, shape or texture of the surface, and Schmidt hammer test is only applicable for flat surface therefore the values won't be correct if the values are to be known on uneven surfaces. Best alternatives to be used instead of Schmidt hammer is core testing method in which a portion is drilled and extracted, which is later sent to laboratory for testing. Thereon the compressive strength values shall be determined accurately.

5.5. Accelerometers

Accelerometers are an essential to measure the accelerations on the bridge in the cartesian coordinate system. The values of accelerations obtained can be then double integrated to find out deflections.

The maximum values of deflection will be found underneath the deck, on the girders at mid span. And positive deflection at the end of spans. Reaching those points beneath the bridge is both difficult and unsafe, these devices need a continuous power supply, so it becomes much difficult to use these devices in remote areas. The main challenge of accelerometer is to place it at the point where most critical data is to be found, which fails most of the times because of inexperienced team or critical points are quite in accessible. Keeping these limitations in mind if following two devices were used it would have been much beneficial in bridge health monitoring process.

5.5.1. Fiber Optic Sensor

These sensors can be structurally installed in the bridge or can be used temporarily while inspection to measure deflections at every point of the bridge and is very useful in covering large distances.[18]

5.5.2. Digital Image correlation

This method uses HD cameras that take photograph before and after loading on bridge which in return gives us strains, displacements, and deformations on bridge being analysed.[19]

5.5.3. Accelerometer

If in any case accelerometer is the only device available at that moment, some certain changes are due while using it. Permanent accelerometers should be attached to the bridge with data loggers installed in it, having permanent sim card in it that would give real time data analysis to the user on the ground.

5.5.4. Internally installed Sensors

When the girders are being cast sensors such as accelerometers be installed in the concrete so that throughout the life of the bridge, health can be measured, and that all data be recorded. As prevention of disasters is better than cure after a large calamity.[20]

5.6. Under water bridge Inspection

The main reason for choosing the site at Takhta baig was because the riverbed of the bridge was dry, and analysis of underwater bridge inspection was difficult due to lack of training and necessary equipment required. If this project is pursued in future following equipment, and training would be necessary:[21]

5.6.1. Driver

The visual inspection of structural elements of bridge imbedded under water that are damaged due to corrosion, cracks and scouring is only possible if it's viewed by physically diving into the river and snapping images of the damages. The following initials are required for this:

- Basic training program for the team of divers who are responsible for looking the damages.
- Divers require waterproof cameras to take images of the damages for later finding the basic remedies required for the retrofitting of bridges.
- Measurement devices and necessary scales are also required by the divers for data collection purposes.

5.6.2. ROV (Remote operated vehicles)

These are unmanned vehicles required for greater depth analysis or places where it is physically impossible to reach. These devices are equipped with cameras and sensors that can send real time images to the operator on the surface.[22]

5.6.3. Sonar Imaging

Sonar imaging technique is commonly used for determining the damages in structural elements of bridge underneath water. The working principle of sonar imaging is that it uses sound waves to create under water structures. This method is use full in determining damages, scours, sediment accumulation and many other different anomalies. [23]

5.7. Conclusion

At the end of our final year project, I would like to comment that Bridge health monitoring system using drones, an AI has proved very beneficial in the field of infrastructure and maintenance of structural elements of bridges. This method has given us a new highway to achieve better and quicker results than those of traditional methods being used since the start that are unable to provide detailed survey and hidden damages of the bridge being analysed, and for detailed survey destructive testing is required.

This new technique is advantageous as it detects early anomalies in bridges, due to early detection of defects timely procedures can be adopted that may require very little maintenance or retrofitting in this regard and a lot of time and finances can be saved.

The pivotal role is played by artificial intelligence, by machine learning algorithms, AI can be useful in processing of large amount of data and enabling us to view data patterns, that in return give us sure predictions of structural element problems, in return bridge health is improved and life span is increased.

Leaving aside the core development in bridge health monitoring system, it has also proven fruitful in development of human ease, as it does not require any physical inspection rather drones are there in this regard, and safety factor has also increased exponentially as inaccessible places are now easily accessible and no dangerous arrangements must be made to be present there in physical sense.

Yet still there are many challenges that still need to be overcome. This methodology is new in the market hence it requires necessary training to inspection teams so that they can handle any type of bridge in least possible time without any damage to sensitive equipment. As all the data transferred from drone and AI software is with the help of wireless data transmission hence proper security and encryption code is required that would help improve the security of data. Necessary standard operating procedures should be made in regard of bridge health monitoring system using drones and AI. Drones should be equipped with weather resistant devices so that it gives its full potential in any type of weather conditions.

A quotation states that “necessity is mother of invention” by taking this under consideration, day by day science is getting revolutionized, and modern equipment and technological advancements have paved the way for better quicker and time saving techniques to accomplish any goal in any field of life. But I would like to say that need for professionalism in an individual can never be taken away by any technological advancement. In the end strength lies in individual who is working for the beneficial future for mankind, one’s belief must be his utmost priority that would give him will power that would open several roads for doing any type of task. If we talk about bridge inspectors, no matter how advance equipment is on his disposal it is him who would find a way to find solution for the problems he is facing on site even if he is in possession of limited resources. No one can be a good Engineer till the time he doesn’t have good problem-solving techniques that can help him solve any type of problem.

References

1. Mahmoud, H. and A. Zafar, *Time-Dependent Reliability Analysis of Reinforced-Concrete Bridges Including Deterioration Effects*, in *Geotechnical and Structural Engineering Congress 2016*. 2016. p. 1354-1366.
2. Khedmatgozar Dolati, S.S., et al., *Non-destructive testing applications for steel bridges.* Applied Sciences, 2021. **11**(20): p. 9757.
3. Ferhat, A. and S. Mehmet, *Correlation between Schmidt Hammer and destructive compressions testing for concretes in existing buildings.* Scientific Research and Essays, 2010. **5**(13): p. 1644-1648.
4. Wang, Q., J.C.P. Cheng, and H. Sohn, *Automated Estimation of Reinforced Precast Concrete Rebar Positions Using Colored Laser Scan Data.* Computer-Aided Civil and Infrastructure Engineering, 2017. **32**(9): p. 787-802.
5. Park, H.S., et al., *A New Approach for Health Monitoring of Structures: Terrestrial Laser Scanning.* Computer-Aided Civil and Infrastructure Engineering, 2007. **22**(1): p. 19-30.
6. Gastineau, A., T. Johnson, and A. Schultz, *Bridge Health Monitoring and Inspection – A Survey of Methods*. 2009.
7. Vaccaro, R., et al., *An Algorithm for Estimating Bridge Deflection from Accelerometer Measurements*. 2006. 540-544.
8. Bridges, T.O.S.o., *The manual for bridge evaluation*. 2011: AASHTO.
9. Shashi, M. and K. Jain, *Use of photogrammetry in 3D modeling and visualization of buildings.* 2007. **2**.
10. Guo, Y., et al., *Deep Learning for 3D Point Clouds: A Survey.* IEEE Transactions on Pattern Analysis and Machine Intelligence, 2021. **43**(12): p. 4338-4364.
11. Alsharqawi, M., S. Abu Dabous, and T. Zayed, *Quality Function Deployment-Based Method for Condition Assessment of Concrete Bridges*. 2016.
12. Zubair, M.J.M., A.B. Vawale, and N.S. Vaidkar, *Literature Review On Analysis & Design Girder Bridge By Using Csi Bridge.* International Journal of Innovations in Engineering Research and Technology: p. 1-4.
13. Mikhail, E., J. Bethel, and C. McGlone, *Introduction to Modern Photogrammetry.* John Wiley & Sons, 2001.
14. Pfeifer, N. and C. Brieseab, *Geometrical aspects of airborne laser scanning and terrestrial laser scanning.* International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2012. **36**.
15. MAHMOOD, S., *OPTIMAL CLOUD TOPOGRAPHIC MODEL BY STATISTICAL EVALUATION FOR LARGE SCALE MAPPING USING GEODETIC TERRESTRIAL LASER SCANNER*. 2019, Universiti Teknologi Malaysia.
16. Putra, E.Y., A.K. Wahyudi, and C. Dumingan. *A proposed combination of photogrammetry, Augmented Reality and Virtual Reality Headset for heritage visualisation*. in *2016 International Conference on Informatics and Computing (ICIC)*. 2016. IEEE.
17. Harris, D.K., C.N. Brooks, and T.M. Ahlborn, *Synthesis of Field Performance of Remote Sensing Strategies for Condition Assessment of In-Service Bridges in Michigan.* Journal of Performance of Constructed Facilities, 2016. **30**(5): p. 04016027.
18. Yue, L.N., S.J. Xiang, and Y. Yang. *The Intelligent Bridge Health Monitoring System Based on Optical Fiber Sensing Technology*. in *Advanced Materials Research*. 2012. Trans Tech Publ.

19. Mousa, M.A., et al., *Application of digital image correlation in structural health monitoring of bridge infrastructures: A review.* Infrastructures, 2021. **6**(12): p. 176.
20. Tennyson, R., et al., *Structural health monitoring of innovative bridges in Canada with fiber optic sensors.* Smart materials and Structures, 2001. **10**(3): p. 560.
21. Browne, T.M., et al., *Underwater bridge inspection*. 2010, United States. Federal Highway Administration. Office of Bridge Technology.
22. Strock, T. and T.M. Browne, *Overview and comparison of nationwide underwater bridge inspection practices.* Transportation research record, 2009. **2108**(1): p. 97-106.
23. Hou, S., et al., *Underwater inspection of bridge substructures using sonar and deep convolutional network.* Advanced Engineering Informatics, 2022. **52**: p. 101545.

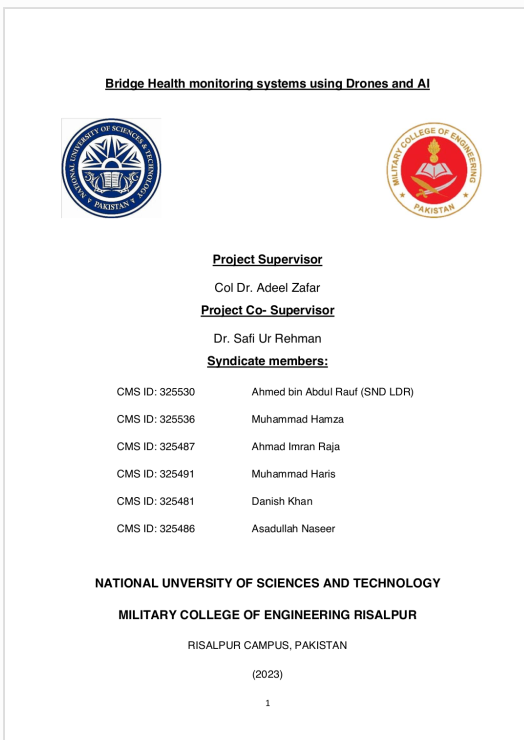
turnitin

Digital Receipt

This receipt acknowledges that Turnitin received your paper. Below you will find the receipt information regarding your submission.

The first page of your submissions is displayed below.

Submission author:	Ahmed Bin Abdul Rauf
Assignment title:	Quick Submit
Submission title:	Bridge Health monitoring systems using Drones and AI
File name:	Final_Thesis_BHMS_Syndicate_1_2023_230612_144202_1.pdf
File size:	2.92M
Page count:	57
Word count:	9,892
Character count:	61,565
Submission date:	13-Jun-2023 02:07AM (UTC-0700)
Submission ID:	2115135253



Bridge Health monitoring systems using Drones and AI

Project Supervisor

Col Dr. Adeel Zafar

Project Co- Supervisor

Dr. Safi Ur Rehman

Syndicate members:

CMS ID: 325530	Ahmed bin Abdul Rauf (SND LDR)
CMS ID: 325536	Muhammad Hamza
CMS ID: 325487	Ahmad Imran Raja
CMS ID: 325491	Muhammad Haris
CMS ID: 325481	Danish Khan
CMS ID: 325486	Asadullah Naseer

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

MILITARY COLLEGE OF ENGINEERING RISALPUR

RISALPUR CAMPUS, PAKISTAN

(2023)

1

Bridge Health monitoring systems using Drones and AI

ORIGINALITY REPORT

9%	8%	2%	6%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Higher Education Commission Pakistan Student Paper	2%
2	Mohammed Alsharqawi, Tarek Zayed, Saleh Abu Dabous. "Integrated condition rating and forecasting method for bridge decks using Visual Inspection and Ground Penetrating Radar", Automation in Construction, 2018 Publication	1%
3	kupdf.net Internet Source	1%
4	www.researchgate.net Internet Source	1%
5	fics.nust.edu.pk Internet Source	<1%
6	Hussam Mahmoud, Adeel Zafar. "Time-Dependent Reliability Analysis of Reinforced-Concrete Bridges Including Deterioration Effects", Geotechnical and Structural Engineering Congress 2016, 2016 Publication	<1%

7	Submitted to Heriot-Watt University Student Paper	<1 %
8	www.mdpi.com Internet Source	<1 %
9	prr.hec.gov.pk Internet Source	<1 %
10	upcommons.upc.edu Internet Source	<1 %
11	www.ewgateway.org Internet Source	<1 %
12	spectrum.library.concordia.ca Internet Source	<1 %
13	Submitted to Universiti Teknologi MARA Student Paper	<1 %
14	Submitted to Universiti Teknologi Petronas Student Paper	<1 %
15	es.mathworks.com Internet Source	<1 %
16	corpus.ulaval.ca Internet Source	<1 %
17	Hemraj R. Kumavat, Narayan R. Chandak, Ishwer T. Patil. "Factors Influencing the Performance of Rebound Hammer Used for Non-Destructive Testing of Concrete	<1 %

Members: A Review", Case Studies in Construction Materials, 2021
Publication

18	Submitted to St. Louis Community College, Florissant Valley Student Paper	<1 %
19	github.com Internet Source	<1 %
20	livrepository.liverpool.ac.uk Internet Source	<1 %
21	Eslam Mohammed Abdelkader, Mohamed Marzouk, Tarek Zayed. "An Invasive Weed Optimization-Based Fuzzy Decision-making Framework for Bridge Intervention Prioritization in Element and Network Levels", International Journal of Information Technology & Decision Making, 2020 Publication	<1 %
22	eprints2.insa-strasbourg.fr Internet Source	<1 %
23	ro.uow.edu.au Internet Source	<1 %
24	Sandeep Sony, Kyle Dunphy, Ayan Sadhu, Miriam Capretz. "A systematic review of convolutional neural network-based structural condition assessment techniques", Engineering Structures, 2021	<1 %

Publication

25	Submitted to Kingston University Student Paper	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		