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# Structural Health Monitoring of Concrete Bridges in Guilan Province Based on a Visual Inspection Method

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**Abstract:** Iran is located in a seismic prone region with several earthquakes occurring annually causing extensive damage to structures and infrastructure. Guilan province is located in the northern part of the country, exhibiting a large population, moderate climate and extensive river system. This region experiences high humidity, several active faults and high seismic hazard potential. This highlights the importance of an active and extensive maintenance and rehabilitation program for the bridges in this region. Structural Health Monitoring (SHM) is an engineering tool used to control changing conditions of infrastructure providing useful information for management, decision making and in certain circumstances code revision. This paper proposes a method for SHM of bridges. In total, 123 concrete bridges were assessed based on this visual inspection; with statistical analysis of results carried out on decks, piles, abutments, restraints and river engineering which effectively addressed the deficiencies in bridges maintenance. Finally some practical solutions are suggested to enhance the performance and lifetime of bridges. Based on the knowledge of the authors, this is the first comprehensive study on a large group of bridges in Iran which can be used as a base for further studies on management and retrofitting of bridges in the region.

**Keywords:** Bridge, Structural Health Monitoring, Visual Inspection.

## 1 Introduction

Infrastructures supplying essential lifelines are a critical component of every society, with the cost of maintenance and rehabilitation of these being significant. Bridges are one type of this infrastructure connecting cities, regions and even countries together. Guilan province is located in the north of Iran, bordering the Caspian Sea with a high residential density and moderate climate. Due to the topography

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of the region, this area has a high density of bridges (approximately 15000 including culverts, short and long bridges) (DRUDGP 2011). Having two major harbors (Astara and Anzali) enabling trade between Iran and other middle Asian countries causes these bridges to exhibit heavy traffic loads. The deterioration of bridges is inevitable, so extensive maintenance and methods reducing the infrastructures deterioration are critically important. Several bridges in these regions were identified to have been constructed decades ago and have had insufficient monitoring and maintenance since. As a result, many of them require urgent attention. Visual inspection has been used as an early method for SHM and condition assessment of bridges. The majority of the decisions in relation to maintenance work are based on visual inspection, even for infrastructure that has been installed with modern equipment including sensors and actuators. Each project is unique requiring its own needs and considerations Using new methods, such as: signal processing, image processing, neural networks, fuzzy logic, damage detection, non-destructive testing (NDT) methods [Wenzel (2008)] and others may lead to the best decision [Enright and Frangopol (1999); Frangopol and Das (1999); Faber and Sorensen (2002); Rafiq (2005); Yonggang, Yulong et al. (2008); Lima, Amiri et al. (2012)]. Little research has been done on SHM of bridges in Guilan Province. Lima and Limaei (2011) studied the SHM of 6 concrete bridges in Rudbar region and discussed the existing condition of there main components. They proposed some solutions to correct the problems observed in those bridges In this paper a comprehensive data collection and assessment on the condition of existing bridges based on visual inspection assessment, has been conducted for 123 concrete bridges in the Guilan province. A methodology is proposed for the visual inspection of bridges based on key categories to assess the bridges elements according to the classification of the adjoining roadway.

## 2 Seismic activity of Guilan province

The Manjil earthquake of 1990 (Ms=7.7 Richter) shocked the Northern Iranian territory causing extensive infrastructure damage and significant loss of human life. Approximately 1100 villages were destroyed in rural areas [Sartipi (2006)]. Historically, Guilan province is an area of significant seismic hazard, with active faults (Table 1) including Manjil-Rudbar [Amiri and Amrei (2008)].

## 3 A visual inspection procedure for SHM of concrete bridges in Guilan Province:

The 123 concrete bridges included in this study were selected based on the following criteria. The names and locations of each of these were not permitted for

Figure 1: Bala Bala bridge – Site of the liquifaction that occured during the Manjil earthquake (1990).

Table 1: Main faults of Guilan province (www.iiees.ac.ir)

| No | Name | Fault Length (km) |
|---|---|---|
| 1 | Manjil-Rudbar | 152 |
| 2 | Talesh | 75 |
| 3 | Fouman | 60 |
| 4 | North Alborz | 300 |
| 5 | Khazar (Alborz) | 600 |
| 6 | Javaher Dasht | 74 |
| 7 | North Qazvin | 60 |
| 8 | Lahijan | 51 |
| 9 | Masoule | 60 |

publication, based on the request of the department governing their maintenance, for strategic reasons. The selection criteria were: 1) Total length of the bridge $\geq$ 30 meters and 2) One clear span was $\geq$ 20 meters. The 123 bridges were then assessed and given a SHM score associated with the summary presented (Table 2). The primary goal of this SHM was to ascertain the condition of these essential infrastructures so that informed decisions could be made with regard to the need for maintenance and/or rehabilitation.

Visual inspection of the condition of each of the main components of the bridges assessed was conducted. These included: river engineering, middle piers, restraints, abutments, water currents and decks (Table 3 to Table 9). This assessment was conducted based on the experience of the examiners, with a score recorded in each of the categories up to the maximum score listed. This was repeated for each of the 123 bridges assessed.

Table 2: Structural health monitoring assessment criteria of bridges in Guilan province based on visual inspection.

| **Health score** | **Bridge condition** |
|---|---|
| **0-25** | Bridge is out of service and traffic must be stopped |
| **25-50** | Traffic is restricted and immediate rehabilitation required |
| **50-75** | Bridge needs essential repair |
| **75-90** | Bridge needs minor rehabilitation |
| **90-100** | Bridge is in good condition and requires normal maintenance |

Table 3: River engineering assessment criteria.

| **River engineering** | |
|---|---|
| Case of inspection | Maximum score |
| Appropriate size bridge | 20 |
| Appropriate location of bridge | 15 |
| Bridge safe from water scour | 15 |
| Bridge has not caused sediment disruption | 10 |
| Bridge does not inhibit water flow | 10 |
| Dredging complete (if required) | 15 |

Table 4: Middle pier assessment criteria.

| **Middle piers** | |
|---|---|
| Case of inspection | Maximum score |
| Quality of concrete pouring in piers | 10 |
| Concrete cover | 5 |
| No cracking observed on piers | 5 |
| No cracking observed on pier cap | 10 |
| Piers are free from water scour | 20 |
| No settlement of piers observed | 20 |

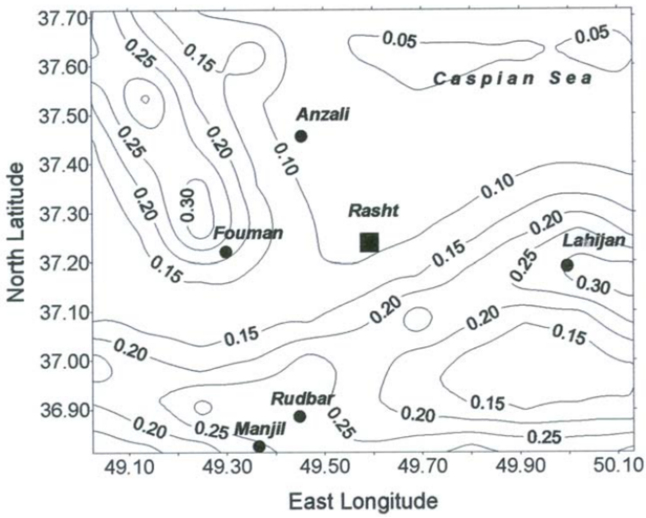


Figure 2: Horizontal seismic hazard (PGA over bedrock) map of Guilan province using logic tree for a 475-year return period [Amiri and Amrei (2008)].

Figure 3: Vali Asr concrete bridge (Rasht–Qazvin freeway).

## 4 Visual Inspection and Analysis:

123 concrete bridges met the selection criteria. These bridges were distributed into 3 categories, based on the road network hierarchy to which they apply. These are as follows and have been presented (Figure 4):

1) Bridges constructed on a highway/freeway;

2) Bridges constructed on main-roads/arterials;

3) Bridges constructed on rural roads.

Table 5: Restraint assessment criteria.

| **Restraint** | |
|---|---|
| Case of inspection | Maximum score |
| Neoprene satisfactory with required thickness | 5 |
| Neoprene is well installed below the beams | 5 |
| Neoprene is in good condition | 5 |
| No plate corrosion | 5 |
| Restraint free of damage | 5 |

Table 6: Abutment assessment criteria.

| **Abutments** | |
|---|---|
| Case of inspection | Maximum score |
| Quality of concrete pouring in abutment | 5 |
| Concrete cover | 5 |
| No cracks observed | 10 |
| No cracks observed in deck | 20 |
| No settlement observed | 20 |
| Deck drainage condition | 10 |
| Concrete slab condition | 5 |
| Concrete cover of slab | 5 |
| Cracking in concrete slab | 10 |

Table 7: Conduct current wall assessment criteria.

| **Current of water** | |
|---|---|
| Case of inspection | Maximum score |
| Quality of concrete pouring in conduct current wall | 10 |
| Concrete cover | 5 |
| No cracks observed | 5 |
| No water seepage observed behind wall | 20 |
| No stone removal due to current | 5 |
| Wall foundation satisfactory | 20 |
| No settlement in wall | 30 |
| Wall drainage system is satisfied | 5 |
| Expansion joints uncompromised | 5 |
| For gabion walls, strength is sufficient against external forces | 5 |

Table 8: Deck assessment criteria.

| **Deck** | |
|---|---|
| Case of inspection | Maximum score |
| Quality of concrete pouring in deck | 5 |
| Concrete cover | 5 |
| No cracks observed in slab | 10 |
| No cracks observed in edge beams | 20 |
| No cracks observed in middle beams | 20 |
| No corrosion observed | 10 |
| Bolts and fasteners well installed | 5 |
| Welds are well constructed | 5 |
| Diaphragms are well constructed | 10 |
| No deflection of lateral members observed | 5 |
| Crossing width is satisfactory | 10 |
| No deflection of beams observed | 20 |
| Deck is satisfactory | 20 |
| Paint condition on guard rail | 10 |
| Drainage system condition | 5 |
| Expansion joint uncompromised | 5 |
| No chemical corrosion on beams | 10 |
| Pedestrian path condition | 5 |
| No excessive vibration during high intensity loading (truck traffic) | 5 |

Table 9: Ratio that implied in main parts of single and multi-spans bridges.

| **No.** | **Main Bridge Components** | **Factor (out of 1)** | |
|---|---|---|---|
| | | **Single Span** | **Multiple Span** |
| **1** | Deck | 0.25 | 0.2 |
| **2** | Abutment | 0.6 | 0.3 |
| **3** | Middle Piers | - | 0.35 |
| **4** | Conduct Wall | 0.09 | 0.09 |
| **5** | Restraint | 0.01 | 0.01 |
| **6** | River Engineering | 0.05 | 0.05 |

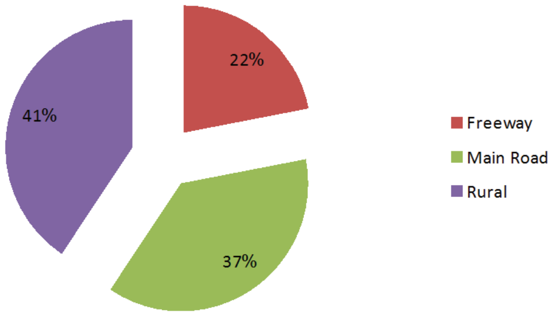


Figure 4: Distribution of bridges assessed based on road hierarchy (%).

The majority of concrete bridges meeting the assessment criteria were on rural roads, however in terms of importance, those assessed on highways and main roads are greater. In addition, as most highway/freeway and main roads are located in plain areas exhibiting abundant sources of sand and gravel; most bridges in these regions are concrete. In the following section, SHM results have been discussed and presented for the 123 bridges assessed.

### *4.1 SHM score of Deck (Multi span and Single span):*

Average scores, based on the assessment criteria above, for SHM of decks in single and multi span bridges are presented (Figure 5a and 5b). There are different factors for single vs. multiple spans (Table 9). Results indicate average SHM values are higher for single span bridges. This is most likely a result of the dynamic loads imposed. The majority of multispan bridges assessed were identified to have improper construction practices that would contribute to the SHM values determined. Assessment of expansion joints confirmed, in the majority of cases, to be filled with asphalt negating the ability of the two decks to behave independently. In general, lacking efficient drainage systems were also noted as a likely cause of damage to the bridge decks assessed. Water discharge pipes used for conveying runoff were ineffective resulting in water scour to the deck body and even pile caps of middle piers. Given the relative importance of freeways and main roads, regular maintenance resulted in overall improved SHM values of bridges in comparison with those in rural areas.

### *4.2 SHM score of abutments (Multi span and Single span):*

The average SHM score of abutments in single and multiple spans of concrete bridges are presented (Figure 6a and 6b). Abutments of single span bridges are

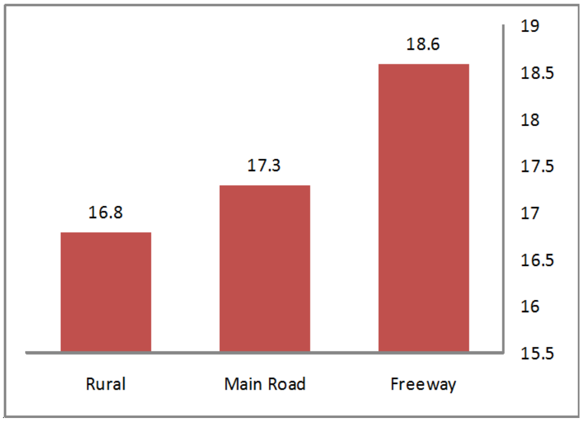


Figure 5a: Average SHM score of decks in single span bridges.

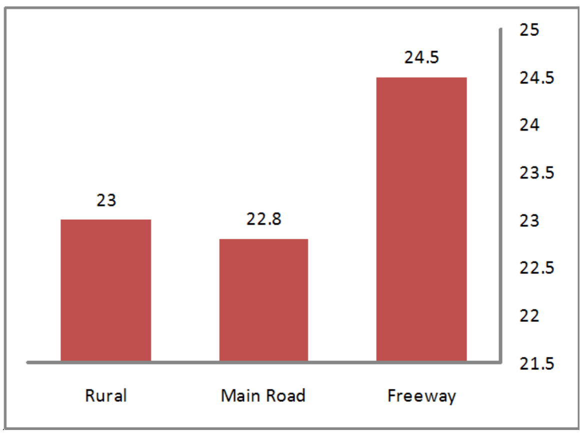


Figure 5b: Average SHM score of decks in multiple spans.

in better condition in comparison to multiple spans. Total health scores of single span bridges are double those of multiple span bridges. In single spans, loads are directly conveyed to abutments in comparison with multiple spans where middle piers also provide structural support. Corrosion, landslide and water scour were in some cases found around middle piers. Systems using gabion or other methods of soil stabilization exhibited less of these issues. The implementation of these is recommended as an effective means for diminishing these issues.

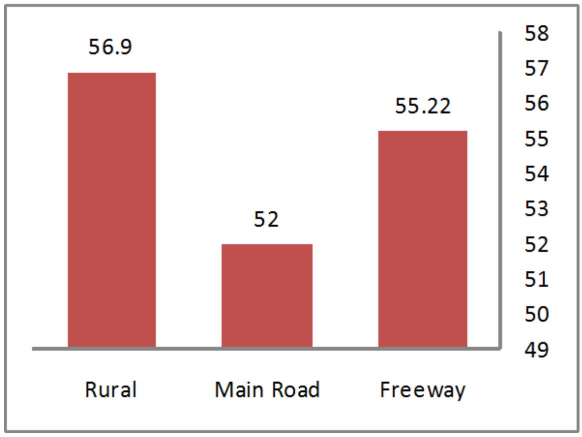


Figure 6a: Average SHM score of abutment in single span bridges (out of 60).

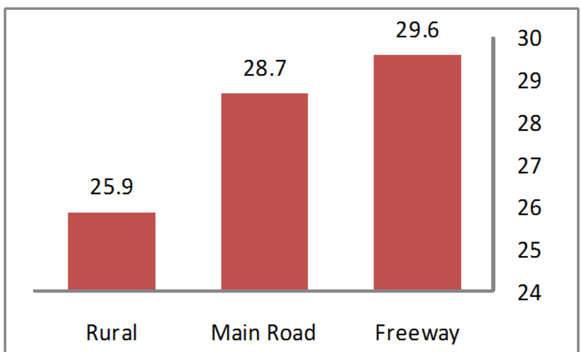


Figure 6b: Average SHM score of abutment in multiple spans (out of 30).

### *4.3 SHM score of middle piers and conduct wall:*

Figure 7a shows the average score of SHM for middle piers. It shows that the condition of piers in highway/freeway and main roads are in good condition based on the assessment criteria used. Piers installed without a good pier protection/scour protection system often display water scour. An example of this type of water scour observed for a pier installed without such protection has been presented from Totkabon Bridge (Figure 8).

Figure 7b presents the average SHM score for conduct walls assessed. Unfortunately, in some cases, there was no conduct wall to assist the flow of water. For these examples, this caused problems during high flow conditions both upstream and downstream. Debris accumulation caused in those areas resulted in water level increases that may lead to further scouring around piers and abutments or in severe cases even landslides and geotechnical problems on the embankment. In freeways and main roads the condition of the conduct wall and flow of water were greater than rural bridges. Changes in local construction practices in recent years have resulted in the inclusion of conduct walls on all bridges in main roads and freeways.

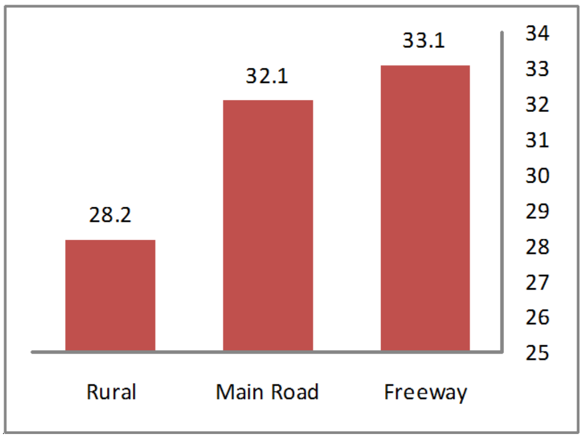


Figure 7a: Average SHM score for middle piers.

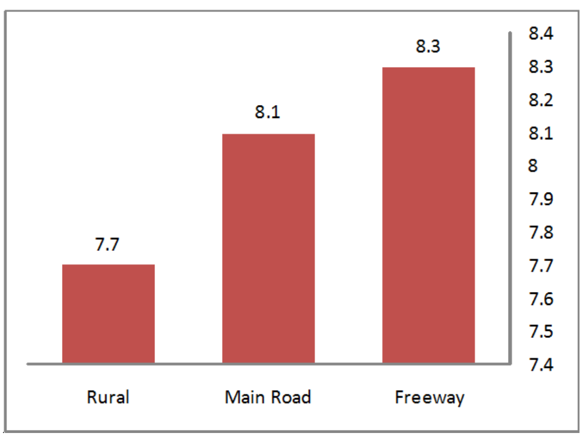


Figure 7b: Average SHM score for conduct wall.

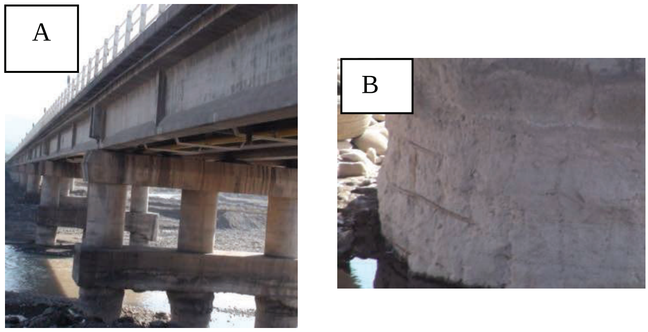


Figure 8: a) Totkabon Concrete Bridge b) Totkabon middle pier water scour.

### *4.4 SHM score of Restraint*

Figure 9 presents average SHM scores of restraints for each road hierarchy. The SHM of restraints in bridges satisfied the limitation. The use of new technologies and materials (neoprene) help to absorb shock and vibration efficiently. In older bridges, some roller restraints were observed. In all cases, the bridges without neoprene restraints scored lower than those with neoprene. Neoprene is a very effective material at transferring forces (especially seismic activity), to the main bridge structure, ensuring the safety and integrity of whole structure.

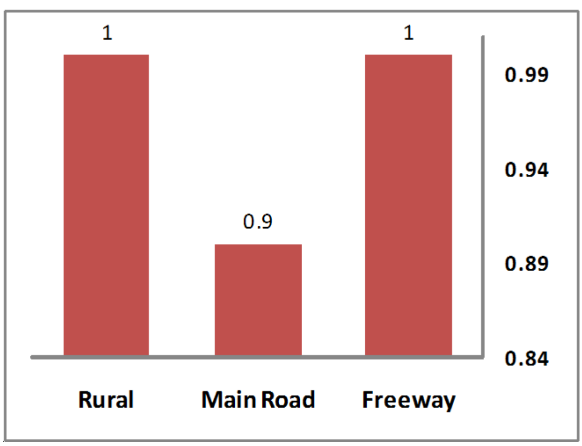


Figure 9: Average SHM score of restraints.

Figure 10a: Type of roller restraints used in older concrete bridges.

Figure 10b: Type of new restraint in concrete bridge.

### *4.5 SHM score of River Engineering*

Figure 11 shows average SHM scores for river engineering. SHM of river engineering satisfied the required standards in freeways and main roads. In rural areas and mountain regions, easy access to dredging was unavailable. In addition most bridges in freeways and main roads have wide spans with water flow uninhibited.

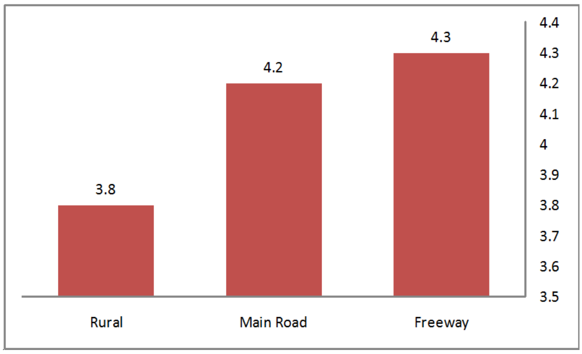


Figure 11: Average SHM score for river engineering.

### 4.6 Total SHM score of concrete bridges

Total SHM score of concrete bridges are presented (Figure 12). Results indicate most bridges in rural and main roads require rehabilitation and maintenance based on the SHM scores discussed (Table 2). Bridges in highways and freeways are in overall good condition. Bridges in freeways and highways are in better structural condition than those on rural and main roads. This was expected due to the majority of freeways and highways being constructed during the last five years using new and modern methods and devices. Increased commercial vehicle loading as well as increased daily traffic loading have both contributed to increased damage and increased required maintenance schedules. Improper maintenance programs and activities were also observed during the assessment period. The primary causes identified to contribute to bridge deterioration included: 1) the use of deformed expansion joints or the compromise of expansion joints as a result of asphalt overlay; 2) Asphalt resurfacing without the removal of existing wearing surface; 3) water discharge pipe blockages from asphalt. Each of these identified issues could be removed as a result of proper maintenance and construction practices.

Compromising expansion joints could lead to catastrophic failure of bridge structural systems as a result of the diminished ability of the system to act independently. In the case of seismic loading this could be particularly damaging. The addition of an asphalt wearing surface without the removal of the existing layer will increase dead loads and act outside the conditions for which the original bridge design was conducted. The result is a lack of predictability as to the behavior of the structural system. This and other factors will also lead to the inadvertent removal of the water discharge system. With an increase in finished surface height as a result of asphalt overlay resulting in discharge pipes being covered, compounding further water damage issues. In addition, the original installation of water discharge pipes were often too short resulting in direct surface runoff to the bridge deck or middle pier pile caps.

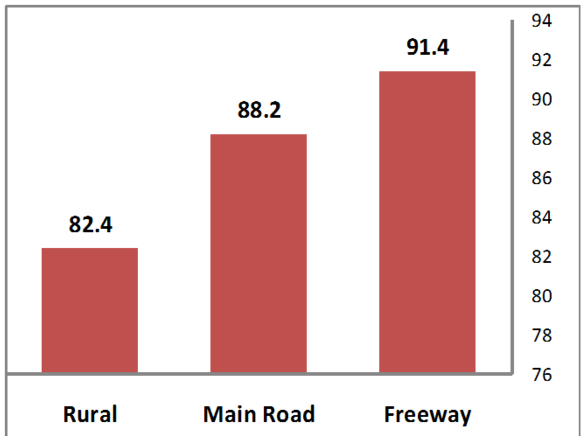


Figure 12: Average Total SHM score.

## 5 Suggestion:

A possible course of action for an effective program aimed at removing a number of the identified issued as a result of the SHM conducted, are included below. Note the suggestions provided in all cases could also be applied to the construction of new bridges to assist in decreasing the required maintenance program.

1. Having an effective and operational drainage system will help increase the lifespan and SHM value of bridges. As Guilan province is located in a moderate region, annually, bridges experience heavy run off. Replacing short drainage pipes with longer pipes to convey the surface water below the pier cap and deck is imperative to prevent unnecessary deterioration. In addition, overlaying new layers of asphalt on a roads surface of a bridge should be conducted with attention to the drainage system and required slope to effectively discharge surface water.

2. Cleaning and maintaining the operation of expansion joints is essential. Inspecting and replacing the rubber joints periodically will contribute to this and decrease dynamic loads transferred between spans enabling them to behave independently and reduce potential structural damages.

3. Adding steel or concrete protection shields in abutments and embankments that are exposed to the water flow will assist the prevention of scour and landslide in those areas. This method is effective for middle piers. Using gabion in upstream and downstream, removing plants and small animals are effective methods for having a flow without causing any damage.

4. Using new construction methods such as neoprene, or devices such as fiber optic or wireless sensors in construction or rehabilitation cases will help SHM and enable more effective maintenance. The introduction of these technologies saves extensive visual inspection field trips removing the subjectivity of the process.

## 6 Conclusions:

In this research 123 concrete bridges in Guilan province were chosen based on the presented criteria. The main parts of those bridges were assessed using a visual inspection procedure. The results indicate that bridges in highways and freeways are in good overall condition, requiring only ongoing maintenance. Most bridges assessed in main and rural roads however, require varying levels of rehabilitation. The deficiencies and probable observed causes are discussed and suggestions made for improving the bridges condition and future SHM.

## 7 Limitations and Future Research:

The limitation of this research is the data acquisition process for SHM. The use of advanced sensors, strain gauges, and other non-destructive health monitoring methods would provide more precise data. A more detailed study could then be supplied using new methods and technology, however a more appropriate budget would also be required. Given the resources supplied for this project the visual SHM process was selected. Future research and funding would supply the alternative methods. The names and positions of bridges would ideally be supplied however this cannot be disclosed as a result of national security and geopolitical importance of lifelines in the region. More in depth research is required to choose an appropriate solution for bridges that require urgent retrofitting.

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