BRIDGE INSPECTION AND MAINTENANCE

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1.0 Introduction

Bridges are key elements in the road network and constitute a major capital investment of a nation's resources. Over time, a bridge will deteriorate and become unsafe for use if no intervention action such as maintenance, rehabilitation or replacement is taken. Bridge failure, either involving a catastrophic collapse or simply the loss of a few critical components, for example, the bridge railings may endanger the lives of public members. Also, because bridges are meant to provide passage over obstacles, any failure of a bridge may limit or severely disrupt the traffic, with consequent inconvenience and economic losses to the community. Bridge inspection, which involves a systematic check on the physical condition of a bridge is effective in preventing these incidents from happening by early detection and arrest of any problems that may otherwise propagate to a critical state.

Another motivation for bridge inspection is in the preservation of capital investment. Due to limited funds there is a need to optimise the available resources. High in the agenda for most bridge owners around the world is an impetuous effort to make the best use of the rare resources by more effective bridge management strategy [1]. To this end, it has become mandatory in some countries, for example, the U. S. A, for bridge agencies to operate a computerised bridge management system (BMS) [2]. A BMS keeps data of all the bridge stocks in a database; and allows informed decisions to be made regarding the management of these bridges. Bridge inspection provides the necessary inputs for the BMS.

A major output of a BMS is a work program enlisting the bridges earmarked for *maintenance and repair* (M&R), *rehabilitation* or *replacement*. *Maintenance* is defined as the work needed to preserve the intended [performance level] of the bridge and to ensure the continued safety of road users [3]. It excludes work leading to the improvement of the structure, whether by strengthening to carry higher live loads or by widening. In BMS maintenance and repair (M&R) are often grouped together as an alternative to bridge rehabilitation which is an extensive repair. For the purpose of this paper, the term 'maintenance' shall be used to include both maintenance and minor repair; i.e., M&R.

2.0 The National Guidelines for Bridge Inspection

In Malaysia, the Public Works Department or Jabatan Kerja Raya (JKR) is the custodian of over 6,000 highway bridges* along the Federal Roads in the Peninsula. The inventory of state bridges has not been completed yet. It is estimated that there are at least as many bridges along the State Roads as that along the Federal Roads. Although it has been a traditional practice for JKR to conduct different levels and types of bridge inspections from time to time, it was not until 1995 that bridge inspection on Federal bridges was made mandatory to all the districts.

In the past, almost all the bridges belong to JKR. With the privatisation of road projects starting 1984 [4] many bridges in Malaysia are now also operated and managed by private companies which recoup their investments from toll collections. Although majority of the privately managed bridges is new the need for a systematic bridge inspection program of these bridges cannot be over-emphasised. Indeed, the regulatory body Malaysian Highway Authority has required that all their concessionaires conduct regular bridge inspection [5].

A working committee under Road Engineering Association of Malaysia (REAM) has been set up to prepare a set of guidelines for bridge inspection. The document is mainly based on JKR's current practices in bridge inspection. It is hoped that the

* Bridges include culverts of span over 0.5 m

guidelines will help ensure the safety of the nation's bridges. Also, these guidelines will help to promote a uniform standard among the various bridge organisations, so that a uniform level of service is assured for all the bridges in the nation. Besides this, sharing of information and resources among these authorities could be more easily achieved when there is a uniform standard of practice.

Many guidelines or manuals on bridge inspection exist from the U.S., the U. K. and Japan. The need for a national standard, which takes into considerations local Malaysian conditions, has often been felt. The REAM guidelines in particular focus more on bridge structures commonly found in this country. Parts of the content of this lecture note will be included in the REAM Guidelines due for completion by December 1998.

3.0 Types of Bridge Inspection

3.1 OECD Classification of Bridge Inspection

Bridge inspection can be classified in terms of the scale or intensity, and/or its frequency of the inspection. Based on this classification, three types of bridge inspection have been identified [6]:

Superficial inspection

A superficial inspection would be carried out by highway maintenance personnel who have a good practical knowledge of road structures, but may not necessarily been trained in bridge inspection. These inspections may or may not be made regularly and will usually occur as the opportunity arises, perhaps during cleaning or routine road or bridge maintenance.

Principal inspection

A trained inspector under the supervision of a bridge engineer would usually make a principal inspection. This type of inspection falls into two categories referred as *general* and *major* distinguished by their frequency and intensity. The *general* principal inspection would be made at intervals of one to two years and would entail examination of elements of the structure against a prepared check list or inspection form. The *major*

principal inspection would be more intensive and would require close examination of all elements, involving the setting up of special access facilities where necessary. The interval between major inspections would vary between three to five years and may be as long as ten years for elements which have shown little or no deterioration since previous inspections.

Special inspection

This would usually be made in connection with unusual circumstances, such as exceptional loading, with occurrence of major weaknesses or with reassessment of the structure against revised specifications and regulations. Such inspections may require a good deal of supplementary testing and structural analysis and will invariably require detailed involvement of a bridge engineer. The special inspection may require supporting investigations of a research character if the background information is meagre and the criteria for assessing adequate performance not well understood.

3.2 Different Purposes of Bridge Inspection

In a broader sense, bridge inspection is the *data collection* stage of the so-called "scientific approach of problem solving" which encompasses *problem identification, data collection, comparing alternatives* and *selection of the best alternative*. It is easy to see the logic of collecting the data prior to comparing the alternatives and selecting the best one among them. In the context of an overall bridge management strategy, bridge inspection involves taking measurements, assessing bridge performance, investigating possible and probable causes of defects, studying feasible courses of remedial actions; etc., in summary, collecting all the necessary data needed for making an informed bridge management decision. Bridge inspection can thus be also classified in terms of the main purpose of the inspection as follows:-

Inventory Inspection

Inventory Inspection is the first inspection carried out on a particular bridge to collect data for the bridge inventory. This type of inspection is done visually and systematically on every bridge in the network. It involves taking dimensional measurements, sketches and photographs of the bridges and entering the data into a computerised database. It

may be very helpful if the design or tender drawings are available. However, because the as-built dimensions of the bridges may differ much from that in the design or tender drawings it is imperative that the dimensions in the drawings are verified at sites.

Since the data would become the basis of decision-making in the context of a BMS and sometimes be used for structural analysis, it is important that the data are free from errors and are as precise as possible. The technician inspector must thus have proper knowledge of taking precise measurements. For example, in measuring the centre-to-centre spacing between two steel stringers it would be advisable to read a measuring tape from the edge of the bottom flange to that of another stringer; and not trying to locate the centre points of the stringers for measurements. As another example, it would be more accurate to determine the diameter of a water main from the measurement of the circumference rather than to measure the diameter directly. Also, the dimensions of a steel section could often be more accurately obtained from a steel handbook. In this case, measurements of the dimensions at site would serve only as a lead to identify the right steel sections from the handbook. These ideas are illustrated in Fig. 1.

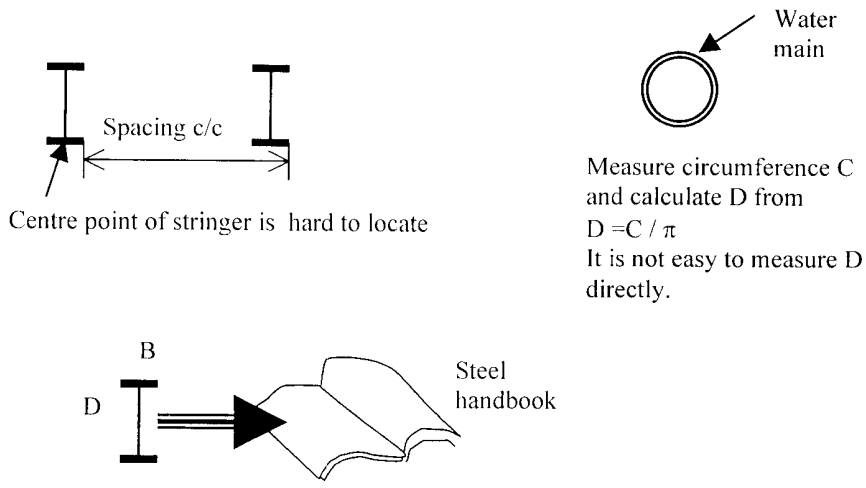

Fig. 1 Examples of how accurate measurements should be obtained

Some of the information needed for the bridge inventory, for example, the year of construction or design loads may be may be obtained from the plaque or imprints on the bridge parapets. Otherwise the needed information have to be inferred or assumed based on whatever information that could be found at the site. For example, the year of

construction and thus the probable design standards used could be inferred from an old newspaper stuck to the underside of the bridge deck.

Condition Inspection

Condition Inspection aims to assess the performance level of a bridge structure and its components. Generally, two types of performance measures have been used: condition rating and load rating. Condition rating assesses the performance level based on physical condition of the bridge whilst load rating evaluates the theoretical safe load-carrying capacity of the bridge. Very often, condition rating is used in a routine bridge inspection while load rating is determined separately in a bridge assessment exercise involving detailed bridge inspections (see Assessment Inspection below).

Condition rating are numerical values from 1 to 5 assigned to each component of the structure based upon observed material defects and the resulting effect on the ability of the component to perform its function in the structure. Sometimes, an overall system rating is obtained either directly by the bridge inspectors or by aggregating the ratings for each individual bridge components and taking into consideration their respective importance. Table 1 gives the rating system for Malaysia [7]. Similar types of rating systems have been used around the world.

Table 1 Malaysian Rating System

Rating	General Definition
0	Bridge part cannot be fully inspected because of access problem, such as submerged structures. Re-inspection necessary whenever possible.
1	No damage found and no maintenance required as a result of the inspection.
2	Damage detected and it is necessary to record the condition for observation purposes.
3	Damage detected is slightly critical and thus it is necessary to implement routine maintenance work.
4	Damage detected is critical and thus it is necessary to implement repair work or to carry out a detailed inspection to determine whether any rehabilitation works are required not.
5	Being heavily and critically damaged and possibly affecting the safety of traffic, it is necessary to implement emergency temporary repair work immediately or rehabilitation work without delay after the provision of a load limitation traffic sign.

Despite the fact that each category of rating in Table 1 has been defined as precise as possible, it may be better to regard the rating system as an ordinal scale from 1 to 5, with 1 represents the 'as new' condition and 5 the worst condition. Condition rating is a function of the extent and severity of the damages/defects found on the components. The REAM Guidelines provide recommendations on how a bridge component should be rated based on the damages/defects that are present.

Condition Inspection can be carried out annually by an inspection team led by a technician who has undergone formal bridge inspection training. Every 3-5 years depending on the conditions of the bridges, a bridge engineer should conduct the Condition Inspection. This arrangement would ensure that a bridge engineer inspects every bridge at least once every few years.

Maintenance Inspection

Maintenance has been defined earlier as the work needed to preserve the intended [performance level] of the bridge and to ensure the continued safety of road users. Ref. [3] classifies maintenance operations as Ordinary Maintenance and Specialised Maintenance operations. Ordinary Maintenance operations are operations of a repetitive nature and in general, technically rather simple. The intervention level for an ordinary maintenance operation is often already established. Specialised Maintenance operations are essentially repair work triggered by the results of a bridge inspection. Common maintenance operations, ordinary or specialised, are given in Fig. 2 [3].

A Maintenance Inspection aims to come up with a program for maintenance and repair (M&R). During a Maintenance Inspection, the damages that are present in a bridge must first be identified. The inspector would appraise the severity and extent of these damages. He would analyse the situation, based on whatever tell tales he observes at site; or his previous experience on similar types of bridges; or the fundamental theory of bridge engineering, to determine the probable causes of the problem(s). He would then evaluate the risk of further deterioration. Finally, he would decide on the maintenance operations needed to overcome the problems.

Ordinary Maintenance Operations

A	Simple cleaning by mechanical means or by hand (of carriageways, footpaths, verges, joints, drains, gulleys, gutters, etc.); removal of foreign material such as trash or parasitic vegetation;
B	Substitution of deteriorated elements by removal and replacement operations (e.g., safety barriers);
C	Small restorations, repointing of masonry and brickwork, replacement of missing stones, sealing and repairs with cement or resin mortars;
D	Localised repairs to pavements and waterproofing, using bituminous materials;
E	Localised painting operations to protect against corrosion (e.g.: safety barriers), renewal of protective treatments on timber;
F	Lubrication and greasing operations (e.g.: steel bearings, machinery on moveable bridges);

Fig. 2a Maintenance Operations [3]

Specialised Maintenance Operations

G	Restoration of concrete (whether or not reinforced) structural parts, to be carried out with different techniques (simple or special cement mortars, synthetic mortars etc.) including, if necessary, prior protection of the reinforcing bars against corrosion;
H	Restoration of brick or masonry structures;
I	Protection of concrete or masonry from degrading action by salts or the atmosphere by means of painting (protective films), impregnation, etc., disinfestation of timber structures;
J	Injection of cement grouts or thermosetting resins into cracks in brick, stone, reinforced or prestressed concrete structures;
K	Injection of cement grouts or synthetic resins (pure or with additives) into sheaths containing prestressing tendons;
L	Maintenance of blots or weldings of metal structures cleaning, greasing and substitution of wearing parts of it;
M	Anti-corrosion protection of metal structures, entailing complete stripping and repainting of part or all of the surfaces;
N	Repair or reconstruction of drainage systems (gullies, channels, collectors and discharge pipes, etc.);
O	Repair or reconstruction of pavements or waterproofing of deck;
P	Repair or reconstruction (partial or total) of expansion joints;
Q	Maintenance of bearings
R	Reclamation operation to river and sea beds to protect foundation from scour and flooded water;
S	Making up settlement on bridge approaches;
T	Replacement of any structural members (mainly timber structures).

Fig. 2b Maintenance Operations [3]

It is evident that a Maintenance Inspection has to be carried out by a bridge engineer who has sufficient knowledge and experience in bridge design and construction; as well as bridge repair techniques and materials.

Rehabilitation/Replacement Inspection

Rehabilitation involves an extensive repair work that may either restore or improve a bridge. A Rehabilitation/Replacement Inspection is indeed a detailed inspection to study the feasibility of rehabilitating the bridge rather than replacing it. The rehabilitation/ replacement decision is very much a subject of study in Decision Science. The issue is whether it would be more economical or beneficial to rehabilitate or to replace the bridge.

In this case, information for both rehabilitation and replacement alternatives are to be collected in an inspection exercise so that a comparison could be made between the two options. These information include the practical aspects of various rehabilitation and replacement options, their cost implications; etc. This type of inspection would go through the same process as outlined above for the Maintenance Inspection: identify problem, appraise severity and extent, analyse the likely causes of problem, propose solutions to the problem, only in greater detail. As such, this type of inspection must be assigned to a senior bridge engineer.

Assessment Inspection

This type of inspection involves a very detailed inspection to collect data for the purpose of computing the theoretical safe load-carrying capacity of the bridge. This is a very specialised job and it often requires use of nondestructive testing equipment in the inspection exercise. The inspector must have access to the structure to enable him to do measurements and to appraise the defects from close range. It is best that the person doing the evaluation would also perform the bridge inspection.

In many instances, dimensions of the bridge needed in the analytical calculations would be taken. The loss of member sections and its impact on load-carrying capacity would need to be estimated. Very often, samples are collected to determine the material properties in the laboratory. In some cases, traffic data may also be obtained from conventional traffic survey or by the use of some advance technique like the WIM (Weigh-in-motion) [8].

The REAM Bridge Inspection Guidelines does not cover load rating as a type of inspection. Rather, the REAM Working Committee on Bridge Inspection treats load rating as an assessment exercise and will soon come up with a separate document.

4.0 Bridge Management System

The different types of inspection as described above are rarely carried out alone. More often than not, to effect a complete surveillance of a bridge calls for a bridge inspection program involving a series of different types of inspections. Even for the same purpose it may sometimes be necessary that the inspectors make a few visits to the bridge site to conduct different levels of inspections.

In particular, a bridge maintenance management procedure must exist in the context of a BMS, which stipulates how the various levels/types of bridge inspections should be carried out to identify projects for maintenance, rehabilitation and replacement. As an example, in JKR's Annual Mandatory Bridge Inspection (AMBI) Program [9], four types of bridge inspections are specified:-

a) Inventory Inspection
b) Annual Condition Inspection
c) Confirmatory Inspection
d) Detailed Inspection

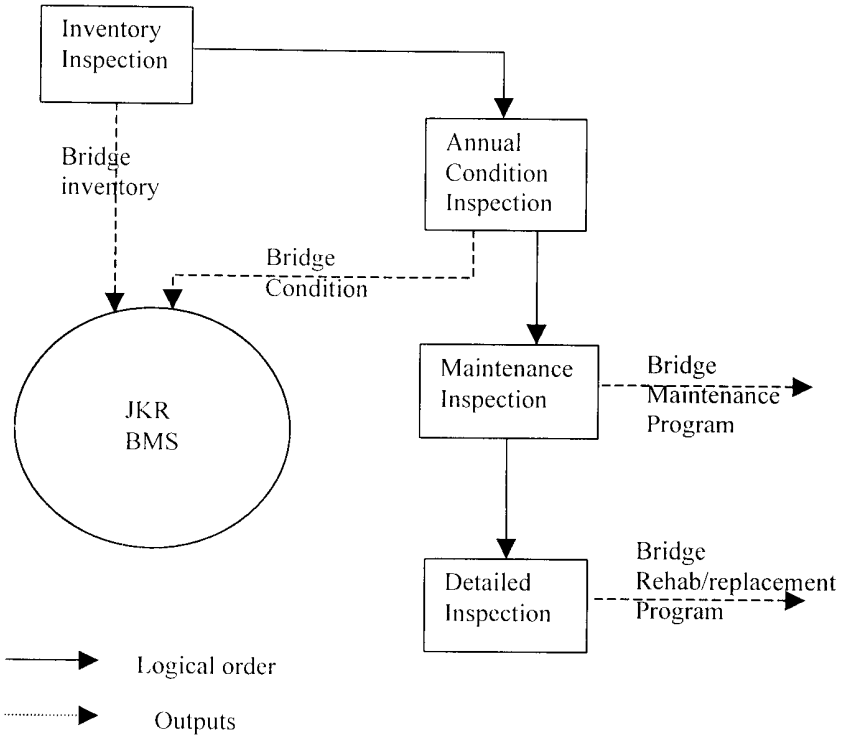

Fig. 3 Flow chart of different levels of inspections

A flow chart showing the order of these inspections and their outputs are presented in Fig. 3. *Inventory Inspection* is necessary for every new bridge or any existing bridge whose inventory has not already been included in the Bridge database. Every year, the JKR district carries out mandatory *Condition Inspection* for the purpose of ensuring that the bridges are safe, functional and well maintained. *Confirmatory Inspection* follows the annual condition inspection and was carried out by Bridge Unit engineers on selected bridges with poorly rated components (that is, ratings of 4 or 5). This inspection was originally intended more for ensuring that the rating done by the district inspection teams are consistent with the established rating criteria. It has since evolved into an exercise for the Bridge Unit to prepare the annual maintenance programs and schedule for detailed inspection. This is indeed a Maintenance Inspection. For bridges that may require either a rehabilitation or replacement work a *Detailed Inspection* would subsequently be carried out.

5.0 Qualifications of a Bridge Inspector

It is clear from preceding discussions that the qualifications of a bridge inspector depends on the purpose and types of inspection, their complexity and the prerequisite knowledge necessary for such inspection.

In general, a good inspectors, whether a technician or an engineer, should possess the general traits as follows:-

- Reliability

Bridge inspections are done at sites away from the office. A bridge inspector must therefore be a dependable person to carry out a task as instructed; and can be counted on to take all the necessary actions in emergency circumstances.

- Technical and Communication Skills

A bridge inspection, regardless of the type or purpose, should include the following steps:-

i. determine if there is a problem
ii. assess the severity and extent of the problem
iii. evaluate any possibility of further deterioration
iv. identify the probable causes of the problem
v. report the inspection
vi. propose solutions to the problem and/or recommend a more detailed and specialised type of inspection

To be able to do the above requires that the bridge inspectors be technically sound. The amount of technical knowledge needed depends on the types and purposes of the inspections. It is important that he has undergone a formal training in bridge inspection. In addition, a bridge inspector must be able to write, draw or verbally communicate his observations to his higher-ups.

iii. Health

A Bridge Inspector must be physically fit and has good eyesight. This would enable him to inspect difficult places without taking unnecessary risks as well as detecting small defects in conditions of varying light and shade. Safety is very important and inspectors must never take unnecessary risks.

iv. Attitude

Bridge inspectors often find themselves in a dangerous, dirty and/or difficult environment. A good inspector must have the right attitude and enthusiasm to do a good job in inspection. He must be willing to inspect items thoroughly and critically in difficult or unusual environment.

v. Inquisitive Minds

Bridge inspection is like a detective work in which the presence of a problem, its severity and extent, and its probable causes; etc. are deduced based on whatever tell-tales found on the bridge structure. An effective bridge inspector should thus possess an inquisitive mind to probe into the problem and establish a logical link between what he sees and what had probably happened.

6.0 Inspection Equipment

In order to carry out the inspection properly bridge inspectors must be properly equipped with inspection equipment. This equipment is needed for measurement, recording, safety and access. A set of this equipment is given in Fig. 4. For more specialised inspection nondestructive testing (NDT) equipment may sometimes be needed.

Measurement Equipment		
1.	5m measuring tapes	For measuring short dimensions
2.	50m measuring tapes	For measuring span length, width and other longer dimension
3.	Plumbob	For measuring degree of tilting
4.	Vernier calipers	For measuring steel thickness
5.	Crack scale	For measuring crack width
6.	Deep sounding apparatus	For measuring river depth and local scour depth; also used for measuring tilt of pier
7.	Spirit Levels	For measuring perpendicular distance to any structural member
8.	Ranging rods	For probing and measuring scour under culvert, piers and abutments
Recording Equipment		
1.	Camera	To take photographs of defects or damages to the structures, and for bridge identification; Camera with zoom lens and flash is preferred
2.	Blackboard	To record bridge number/name while taking photographs for bridge identification; should be supplied with chalks and duster.
3.	Clipboard	As a hard surface to write on when filling forms
4.	Writing paper	For drawing sketches
5.	Markers, pens & pencils	For marking and writing
Safety Equipment		
1.	Safety jacket (fluorescent)	To be worn at all times during inspection
2.	Safety helmet	To be worn at all times during inspection
3.	Safety boots	To be worn at all times during inspection
4.	Life jacket	To be worn when inspecting over waterways
5.	Traffic sign boards & cones	To be installed for traffic control
6.	Safety belts	To be used when climbing the structure
7.	First-aid kit	For first-aid treatment of any injuries
8.	Goggles	To protect the eyes while looking under deck
9.	Overalls	As a protective clothing

...contd.

Fig. 4a Bridge Inspection Equipment

Access Equipment		
1.	Ladder	For access to soffit, bearing, walls, etc.
2.	Binoculars	To be used when there is no access to the structure
3.	Boats or inflatable dinghy	For access to river piers and spans
4.	Tapping hammer	For tapping the concrete surface in order to determine the soundness of the structure
5.	Chisel & electric drill	For removing the concrete for tests
6.	Parang	For clearing bushes, branches, weeds, etc.
7.	Flashlights	For lighting dark areas
8.	Shoulder bag	For holding equipment
9.	Ropes & harness	For tying and climbing

Fig. 4b Bridge Inspection Equipment

7.0 Safety During Inspection

Bridge inspections can be dangerous if the inspector is not careful. A vehicle may hit a bridge inspector while on the bridge. He may fall from the bridge into a river. Wild animals or insects may harm him. As such, a bridge inspector must always bear in mind 'Safety first' during his planning and conduct of the inspection. A few safety rules are presented here:

- Always carry with you signs such as "AWAS" and "PEMEREKSAAN JAMBATAN SEDANG DIJALANKAN", or similar signs which will warn drivers.
- Always put on a reflective jacket.
- Protect the work area with cones, have assistants control the traffic or close the road for a short time, if necessary.
- Never inspect a bridge alone.
- Keep a look out for animals and insects that may harm you.
- If you have to go into enclosed places, such as inside a box girder, make sure that there is a flow of fresh air.
- Use proper and safe access for inspection.
- Regularly service and check the inspection vehicle.

8.0 Bridge Inspection Procedures

Bridge inspection is the process by which information on the structural and physical condition of a bridge and its immediate surroundings is collected. The inspection exercise involves identifying and quantifying the damages and deterioration caused by applied loads from various sources, its intrinsic weakness and by chemical influences imposed by the environment.

The procedures involve three stages: 1) Planning for inspection, 2) Conduct of inspection and 3) Reporting.

Planning for Inspection

Before an inspector proceeds to the site for inspection he should do a desk study which includes finding out all available data about the bridge to be visited. Some of the data are available in the bridge database or inventory cards. If a few bridges are to be inspected a schedule must be planned and prepared.

From the available information the inspector would consider the most suitable form of access to use. He would make sure to bring all the needed equipment with him.

Conduct of Bridge Inspection

Prior to an inspection the bridge inspector must make sure that he is at the right and that he has observed all the necessary safety precautions. He would then proceed with the inspection either following a standard checklist or to suit the site conditions. An inspector must know what and where to look for in an inspection. A general guide is given in Fig. 5.

At the end of the inspection and before leaving the site, the inspector has to ensure that the checklist or standard forms are completely filled out, photographs taken are clearly recorded and sketches made are appropriately labeled. He has also to ensure that he does not leave behind his inspection equipment - or his partners.

Main beam:	Detecting corrosion, rupture, abnormal noise, deformation, sedimentation.
Deck slab:	Detecting corrosion, deformation, etc.,
Abutments:	Detecting corrosion, rupture, deformation, scouring, defects (section loss).
Bearings:	Detecting corrosion, freezing etc.
Drainage:	Detecting water leakage, sedimentation, clogging defect (missing drainage pipes or inadequate pipe length).
Sidewalk/kerb:	Detecting sedimentation, defects (damaged or missing precast panels), etc.,
Railing:	Detecting rupture, paint deterioration, deformation, etc.
Pavement:	Detecting pot holes, rutting, settlement, piping failure, etc.
Expansion Joint:	Detecting rupture, abnormal spacing, water leakage, abnormal noises, etc.
River bank:	Detecting erosion, defects (illegal waste proposal, shack, pen), etc.

Fig. 5 A general guide for bridge inspection

Reporting

The results of an inspection must be reported to the higher-ups so that the necessary actions can be decided and taken. The format of reporting depends on the types of inspection and largely the qualifications of the inspectors. For inventory inspection and condition inspection involving technicians as bridge inspectors more guidance must be given to the inspectors. Very often checklists and standard forms are used. For inspections involving bridge engineers, there is no standard format to adhere to. Indeed, the format to be adopted depends more on the intended readers.

Notwithstanding, there are a few basic information which must be included in the report:

- Names of inspectors,
- Date of inspection,
- Objectives of inspection,
- Observations & photographs
- Recommendations

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