- structural underperformance.

Moreover, average annual rate of bridge failures and collapses in the USA are 150-200 spans per year and most collapses are traced to inadequate inspection. Current state-of-practice of bridge maintenance in the USA is such that it does not preserve acceptable structures. At present, bridges are generally rated and monitored during scheduled inspections, largely using visual inspection techniques. There is the possibility that damage could go undetected at inspection or that growth of cracks in load-carrying members to critical levels, for instance, could occur between inspection intervals. Sudden damage leading to bridge collapse also occurs due to collision, as evidenced by the recent AmTrak railroad bridge collapse in the Southeastern US in 1993 involving collision of the bridge by a barge. According to the recent survey in the USA, more than 13% of identified failures of US bridges since 1950 are attributed to collision.

5.17.2 Static Proof Load Testing.

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Quasi-static proof load testing is considered a well proven, reliable approach for the evaluation of a repaired or strengthened structure's load-carrying capacity. It has to be stressed that although this method belongs to the group of non-destructive test, proof loading may sometimes result in damage or even the failure of a tested structure. The term **proof test** usually implies

1. a single test conducted once in the life of a structure (most often prior to being commissioned in service and/or after the repair or strengthening) or

2. a test performed periodically to re-certify that the structure is safe for continued operation.

The key point is that, (in both cases) equivalent working loads (or higher) are generally used.
A typical example is when a structure designed for one type of use and thought to be adaptable to use for another loading condition is certified for that condition by quasi-static proof test. Quasi-static proof testing may also be required for example because of changes caused by the repair work or changes in the load paths.
There are two main categories of structural proof-load tests; *active* and *passive*. A load test that is used as a tool to assist in the design of a repair or strengthening of structures is called active testing. A load test applied to an already repaired/strengthened structure for the purpose of checking that it has adequate strength or stiffness for continued or modified service conditions, is called a passive quasi-static proof-load test.
As noted above, the term proof testing implies that the design loading conditions will be applied to the structure and it is typical that the loading is increased by some factor to allow for unknowns in the design process. Thus, it

is assumed that a proof test will exercise a structure to conditions greater than expected in its service life. (That is, a structure will operate at levels lower than the proof test conditions.) However, it is difficult to actually perform a proof test that exercises each element, sub-element, connection or joint to conditions greater than expected in service with typical margins of 1.15, 1.25 or 1.5 times the maximum service loads. Only by performing a rigorous and exhaustive set of tests could each part of a (non-simple) structure be tested to the required proof test levels.

Not all structures will require proof testing, however such test are sometimes needed to satisfy, national standards and company or organisational requirements for certain structures. In certain cases, quasi-static proof testing is the only available solution particularly if analytical evaluation of the repaired or strengthened structure is inappropriate due to lack of detailed information and/or inaccessibility of structural components for inspection. These proof tests give demonstrated evidence that the structure will meet its design intent and expected service conditions with some additional margins.

In order to conduct the right sort of proof test on a recently repaired structure before it is finally approved for use, certain decisions have to be made. These include

1. deciding upon the form of the appropraite equivalent loading system. This applies to static, dynamic, vibration and fatigue load conditions and whatever else could be considered as a likely source of stresses in the structure. In most cases the load is delivered by placing weights (either in the form of water, sand bags or some other form of *kentledge*) on carefully chosen loading points. It could also be applied through (displacement controlled) hydraulic actuators reacting against a structural frame. In this latter case the loads can be transmitted through load cells which monitor the level of applied force. In general it can be said that the loading system selection depends on the type and position of expected load.

2. deciding upon the level of the induced load. As noted earlier, the applied loads should generally be larger than the service loads for which the structure has been designed. The actual required proof load magnitudes vary in code provisions and their basis has not been well documented. Most suggested service load factors vary between $1 - 1.5\times$dead load and $1.2 - 1.75\times$live load.

   Differences reflect mainly variation of subjective judgement. A pressure vessel is an example of a structure which is typically designed with a desired working pressure and a required proof pressure that is $1.5\times$ the working pressure.

3. deciding on what should be measured during the test. The choice of whch sensor is to be used to measure test data will clearly depend on the range of value expected. Careful positioning of the sensors is vital for a meaningful interpretation of the test behaviour.

Measurement of deflections is usually carried out by displacement transducers. Considerable care is required to ensure that they are properly calibrated, both before and after the test. Displacement transducers can be of many different types but the two most frequently used are the inductive and resistive transducers.

Strains in concrete (and accessible reinforcement; external reinforcement or previously strain-gauged embedded reinforcement, for example) are usually monitored by electrical resistance foil type strain gauges. Strain gauges are currently produced for many different applications and environment conditions. Particular attention has to be paid to their positioning (including orientation).

Initial cracking is usually observed by so-called *crack detectors*. The most common are those based on the principle of changed resistance or voltage due to crack initiation. Established cracks, if accessible, can be measured by either optical readers or by positioning short displacement transducers across a crack. Demec gauges offer a low-cost alternative but their use generally slows down the test programme.

We have seen that one way to test for integrity of a structure is to apply a static load and observe the nature of the resulting deflection. In some circumstances it is possible to apply large static loads to civil engineering structures particularly dams and bridges, but such exercises are expensive and disruptive as well as potentially damaging. Earlier, it has also been shown that non-destructive testing (NDT) techniques have been devised for certain types of structure and material, but these can be very time consuming and are usually confined to localised investigations and to smaller components or structures. Static truck-load tests have been widely used to verify analytical models of bridges and estimate their additional load-carrying capacity. However, such tests do not lend themselves as convenient tools for integrity monitoring unless they are conducted in conjunction with extensive and expensive instrumentation which is often not suitable for systematic and frequent structural integrity monitoring programme. Critical drawbacks are also difficulties in reliably measuring small displacements and average strains under field conditions.

5.17.3 Dynamic testing

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Because of these limitations, non-destructive techniques that use vibration characteristics of structures of all shapes, sizes and materials are becoming increasingly popular. The most obvious reason for this popularity is that vibration measurements are much easier to be instrument which dramatically reduces field work costs. For example, relatively cheap transducers not requiring fixed reference point (e.g., expensive scaffolding), such as seismic piezoelectric accelerometers, are typically used in civil engineering vibration measurements. However, structural vibration response analysis is much more complex than the static and specialist knowledge is required for measurement interpretation.