Sétra

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Technical guide

Loading tests on road bridges and footbridges

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RÉPUBLIQUE FRANÇAISE

ministère des Transports de l'Équipement du Tourisme et de la Mer

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Loading tests on road bridges and footbridges

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Contents

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1 – The objective of the test

1.1 – Purpose of this guide

This guide is intended for clients, project managers, and engineers in consultancies, engineers and laboratories who are responsible for commissioning, designing, organizing, conducting and interpreting loading tests on road bridges ant foot bridges prior to their acceptance. It must also provides the basis for a normative document to accompany Eurocode EN 1991-2. Until they become law, the recommendations in this guide should be stated in the contracts drawn up between participants and the client. To this end, its different chapters all specify the role of each party. Model clauses for engineering and works contracts are given in the annex.

1.2 - The tests and the acceptance of structures

Acceptance is the act by which the client states that it has accepted the structure with or without reservations (Article 1792 of the Civil Code). The date acceptance takes effect marks the beginning of:

- the contractual guarantee known as the "completion bond" described in article 44-1 of the *Cahier des Clauses Administratives Générales* – CCAG (the CCAG is a document that specifies the administrative contract provisions for a given category of contract),
- the responsibilities described in article 45 of the CCAG which result from the principles that underlie articles 1792 and 2270 of the Civil Code and which relate to the "decennial responsibility arrangement",
- specific contractual guarantees (for example corrosion protection) described in article 43-3 of the CCAG.

The "completion bond" which binds the contractor for one year starting from the date of acceptance covers the repair all the disorders notified by the client either in the reservations mentioned in the acceptance report or by writing in the case of those detected after acceptance. In this connection the contractor must:

- perform the finishing works or services or the repairs specified in articles 5 and 6 of article 41 of the CCAG
- correct all the disorders notified by the client or the project manager that appeared or were observed after acceptance such that the structure once again complies with the requirements of the contract,
- perform any strengthening or modification works which are revealed to be necessary as a result of tests conducted in accordance with the Cahier des Clauses Administratives Particulières – CCAP (the CCAP is a document that specified the administrative contract provisions for an individual contract),
- present the project manager with the plans of the structure as constructed as laid down in Article 40 of the CCAG supplemented by the CCAP.

The decennial responsibility arrangement covers all damage which threatens the solidity of the structure or which makes it unsuitable for its intended use and which was not apparent at the time of acceptance.

The contractual responsibility of the contractor may also be brought into play in the case of disorder which is not covered by the decennial responsibility arrangement that is caused by a failure to comply with the contract (poor reinforcement cover, ineffective waterproofing layer, exfoliation of paint, etc.), gross negligence or a fraudulent act.

Any defects and nonconformities which were apparent at the date of acceptance but which were not the subject of reservations mentioned in the acceptance report cannot be called into question subsequently by the client which is considered to have accepted them. This illustrates the importance of acceptance and the operations associated with it in relation to the decennial responsibility arrangement and the other guarantees. The CCAG -Travaux specifies that the contract manager will accept structures on the basis of the report on the operations performed prior to acceptance and the proposals made by the project manager. The operations performed prior to acceptance will include, in particular:

- an inspection of the structures that have been built,
- the loading tests laid down in the CCAP, and any additional tests that provide a means of assessing the quality of the works,
- inspections of the structure, conducted jointly with the contractor before, during, and after the loading tests which will result in a record of any imperfections or defects.

It is strongly advised that, in addition to these three examinations, an Initial Detailed Inspection should be performed as described in the Technical Guidelines for the Monitoring and Maintenance of Engineering Structures (Instruction Technique sur la Surveillance et l'Entretien des ouvrages d'Art – ITSEOA) of 1979 amended in 1995. The costs of this operation will be borne by those responsible for construction and not the future manager of the structure.

Occasionally, the length of time required to conduct an IDI is incompatible with the timeframe for the acceptance operations which are described in article 41 of the CCAG. There are two possible ways in which acceptance can be linked to the outcome of the IDI:

- the duration of acceptance operations can be increased by departing from article 41 of the CCAG,
- acceptance can be made conditional on the conclusions of the Initial Detailed Inspection, which means acceptance can be postponed if the IDI reveals problems.

Furthermore, it is worth pointing out that the conformity of a structure with the requirements of the contract should be verified throughout construction not just at the time of acceptance.

1.2 - The objectives of the tests

The objectives of the tests are as follows:

- to assure the client that the delivered structure well supports the test loads, and, by extrapolation, provide its ultimately intended bearing capacity. To this end, in particular, it is required that no observable damage to the structure occurs when lorries that simulate the test loads specified in Chapter 2 pass over the bridge. The footpaths and adjacent fills may also be tested and will be subjected to appropriate loads. Verification of the serviceability of structures which are sensitive to dynamic effects, such as bridges with wide spans (>200m), cable bridges and footbridges requires their dynamic behaviour to be tested,
- to verify that the mechanical behaviour of the loaded structure conforms to its design modelling. To do this various measurements which are representative of the behaviour of the bridge are made. This is simply a question of verifying that the measurements remain within an acceptable range taking into account the uncertainties that affect measurement, modelling and materials. For some common types of structure the loading tests may be simplified (see Chapter 0),
- to provide one of the elements in the description of the reference state of the bridge which may be essential in order to make a diagnosis in the event of subsequent problems. The future manager of the bridge should be as fully involved as possible in the operations that precede acceptance. The tests must be reproducible and the results must be recorded in the bridge documents. Tests on bridges should include, in particular, inspection before and after loading and, more generally, the results of measurements which are significant with regard to the behaviour of the structure as a whole and the response of the materials under test loads. Noticeable defects can be identified on the basis of observations made before, during and after the tests.

1.3 - Regulatory context

Currently, tests on bridges are governed by:

- the CCAG – Travaux, article 38 of which states that when tests and checks on bridges are specified in the contract the costs will be borne by the contractor (the same is stated in article 41: operations prior to acceptance),
- fascicle 61 heading II chapter V which lays down the main contents of the test programme (article 20-3 and commentaries).

Fascicle 61 heading II also states the purpose of the tests, which is "*to verify the correct design and construction of bridges by examining their behaviour under normal loads*". It lays down the test programme which includes the following stages:

- application of the specified loads,
- detailed inspections of the bridge, before, during and after application of the loads,
- measurement of deflections and the levels of the bearings,
- any useful measurement suggested by the project manager.

Fascicle 61 heading II is soon to be replaced by Eurocode EN 1991-2 with the exception of Chapter V which deals with the tests which will remain part of the national annexes for a certain length of time.

The test loads specified in this guide only apply to bridges that have been designed using the Eurocodes.

1.4 - Bridges subjected to testing

All bridges must be tested according to the conditions laid down in this guide, except in the case of ministerial derogation. The date of the tests is fixed by the project manager and they are to be carried out in application of an administrative order in the presence of the project manager or its representative.

For short bridges, for example closed frame reinforced concrete bridges less than 10 metres in length or covered by a large depth of fill (at least 1.5 metres or more than a quarter of the span), simplified tests can be performed which do not involve physical measurements. The instructions in Chapter 0 should be followed.

In the case where the same contract deals with the construction of several bridges of the same type (similar structures and spans using the same materials and the same contractor), the project manager will lay down the test programme in accordance with the following conditions:

- ten per cent of structures, and obviously at least one, will be subjected to all the tests,
- the tests can be simplified for the other structures, in particular by reducing the number of physical measurements that characterize the operation of the structure.

Bridges or sets of bridges which are of a specific type (movable bridges, bridges with a span exceeding 200 metres, suspension or cable-stayed bridges, footbridges, etc.) must undergo a special programme of tests specified by the CCTP (the CCTP is a document that specified the technical contract provisions for an individual contract).

1.5 - Repaired or strengthened bridges

In the case of repaired bridges it is frequently appropriate to reproduce the same test loads that were used for acceptance purposes in order to assess the quality of the repairs by comparison.

For strengthened bridges to be able to withstand the loads specified in the Eurocodes, the recommendations contained in Chapter 2 must be observed. For strengthening works intended to permit the passage of heavy abnormal loads the level of loading may depart from the recommendations in Chapter 2 in order to approach the level of loading of these anticipated future loads.

In general, the test programme described in the following chapters may be modified on the basis of the following principles:

- only tests that relate to the purpose of the repairs and strengthening are necessary,
- preliminary loading of bearings to achieve settlement is unnecessary
- specific measurements and instrumentation which relate to the purpose of the repair or strengthening works may be added in order to evaluate their effectiveness (for example checking there is no movement at a crack or joint or a mortar free joint that has been compressed by additional prestressing).

2 - Test loads and physical measurements

2.1 - Pavement loads

The pavement test loads will include static loads and moving loads. The test loads will be formed and organized with normal road vehicles.

2.1.1 - General static loads

The serviceability of the bridge is measured by subjecting the deck to traffic loads that represent the action of traffic levels with a return period of between one week and one year. The intensity of these loads will significantly stress the structure without any risk of damaging it. In practice, the effects of the test traffic loads must be between the effect of frequent traffic loads and three-quarters of the effects of the characteristic traffic loads defined in Eurocode EN 1991-2, without, however, being less than the effects of a load of 2.5 kN/m^2 evenly distributed over the pavement.

For bridges which are able to carry heavy abnormal loads, no specific loading test is required with regard to such loads. Bridges which are intended to carry extremely heavy abnormal loads (classes D and E) may nevertheless be subjected to special test loads. This document does not deal with this point.

For bridges which are sensitive to natural phenomena such as temperature or thermal gradient, it is necessary to make sure that the cumulative effect of these with the maximum forecast values on the test day in combination with those of the test loads does not exceed 0.9 times the effects of the design combination. This means that it is necessary, particularly in the case of prestressed concrete structures, to install temperature probes.

Loading tests must include a verification of the mechanical operation of the load-bearing members of the deck. In the case of paved beam bridges, for example, this verification requires tests under midspan loads and under off-axis loads, generally without the need to test each beam.

It is necessary to calculate the stresses that are generated by the test loads. In practice, for decks which work mainly in flexion, more attention is paid to those parts of the structure which experience the greatest flexural stresses, which are referred to as "principal sections". Generally, this is one section for each span and sections on intermediate bearings. In the case of some structures, it may be necessary to check the behaviour of other structural members. For example, for bridges which are highly curved or skewed it might be desirable to check that no lifting of the bridge bearings occurs.

Stationary test vehicles are to be placed on the carriageway. These may be moved close to each other either longitudinally or transversally, irrespective of the lane divisions on the carriageway (Figure 1).

Figure 1: *Loading the first span of a slab bridge.*

To simplify conduct of the tests, and to avoid undue overloading of one section of the structure, it is necessary to limit the number of test vehicles on each test section. It may thus be accepted that the stresses generated by test loads in a few "principal sections", in particular sections above intermediate bearings, will possibly be 10% lower than the stresses caused by frequently occurring traffic loads.

In most cases, the test loads will be formed by a group of lorries which are gradually moved along the structure, thereby allowing the principal sections of a main beam to be tested in turn. Testing sections that are above intermediate bearings may require some additional loading cases. For some positions of the groups of lorries, a few physical quantities which are significant with regard to the operation of the deck will be measured, which makes it possible to trace a pseudo line of influence of the quantity measured on one or more principal sections under the effect of this group of lorries.

2.1.2 - General dynamic loads

For most structures, dynamic effects will be monitored qualitatively by performing simplified tests under moving loads:

- A number of vehicles equal to the number of lanes will be selected from among those used for the static loading tests, giving preference to those with the heaviest axles. These vehicles will be positioned side by side facing in the same direction and will be moved from one end of the bridge to the other at a safe speed,

- A braking test can be conducted on the structure using a heavy vehicle weighing more than 19 tonnes. This test can detect abnormal movements (compression of joints, irreversible deformation of bearings, etc).

For structures which are sensitive to dynamic phenomena, such as bridges with large spans (> 200 m), cable bridges and some footbridges, the first natural frequencies of the deck which are likely to be excited by a dynamic force (wind, pedestrians) should be measured as should the damping of the corresponding modes and the local deflection in order to validate the theoretical modal analyses. The excitation load, the maximum tolerable measurement error, the number of sensors and the number of modes to be measured will depend on the forecast sensitivity of the structure to dynamic phenomena.

2.1.3 - Local traffic loads

For local loads, the effects of the traffic test loads must be between the effects of frequent traffic loads and three-quarters of the effects of the characteristic traffic loads defined in Eurocode EN 1991-2.

This test targets those members or parts of the structure for which the significant values of the effect to be measured require the test loads to be concentrated within a short distance. This involves, for example:

- cross girders and metal brackets,
- the suspenders of bridges with suspended decks
- zones located at the angle of skew slab decks.
- paved cantilevers which extend more than 1.50 metres beyond the edge beam.

In the case of repeated structural members a significant number (about 10%) should be loaded, except under particular conditions.

For flexible members (metal brackets, for example), these tests may be supplemented by measurements and monitoring of the longitudinal profile at the edge of the deck under general test loads in order for any defects to be revealed by irregularities in the longitudinal profile.

In the case of members that are subjected to major stresses caused by local loads and general loads acting at the same time, the local loads should be left in position while the tests involving general loading of the pavement are performed.

2.2 - Footpaths and cycle lanes

Testing of the entire footpath is not required for bridges whose main beams support both the carriageway and the footpaths. The only requirement is to test the local strength under test loads. The intensity of the local test loads must generate effects which are between those of frequent loads and three-quarters of the characteristic loads defined Eurocode EN 1991-2.

In the case of footpaths which are not separated from the carriageway by a safety device or a barrier kerb and for bridges in urban areas, the test load, if one is required, can in certain cases consist of lorries that move along the footpaths.

In the case of footpaths which cannot be accessed by road vehicles, localized tests will be conducted on footpaths, cycle lanes and the strips that separate the two, by placing a weight on part of their surface (**Figure 2**).

Figure 2: *Placing a load on a pavement.*

The surface area to be subjected to loading, in several sections, is equal to one-tenth of the total surface area and the loaded length of each section should attain approximately three times the width of the footpath or cycle lane.

2.3 - Pedestrian and cycle bridges

Both static (**Figure 3**) and dynamic tests are to be performed in the case of bridges which are used exclusively by pedestrians and cycles.

Figure 3: *Static tests on a footbridge.*

In the case of static tests, the load will consist of weights, or if possible vehicles with an appropriate weight, and should generate stresses that are between the effects of frequent traffic loads and three-quarters of the effects of the characteristic traffic loads defined in Eurocode EN 1991-2.

The loading tests must include the verification of the good performance of the deck as regards bending, swaying and twisting.

In the case of dynamic loading tests, the instructions in section 2.1.2. should be observed, noting that the bending modes between 1.6 and 2.4 Hz and the swaying modes between 0.5 and 1.5 Hz are the most likely to be excited by the passage of pedestrians. For structures which are particularly sensitive, the maximum acceleration of the principal modes will be measured under excitation which is representative of the passage of pedestrians. These values will then be compared with those obtained on the basis of the serviceability criterion in the Eurocodes.

2.4 - Measured physical quantities

The following can be measured: deflections, settlement (of bearings), horizontal displacement of bearings (**Figure 4**), at the top of an inclined leg or the top of a tower, flexural rotation (at the base or the top of an inclined leg), strain (strain gauge in the case of metal beams, non-opening in the case of mortar free joints), curvatures, tensions (suspenders, stay cables).

Figure 4: *Sensors for measuring displacements on a bridge bearing.*

The quantities that are measured must be significant with regard to the uncertainties that relate to their determination and measurement. They must characterize the behaviour of the structure as well as possible.

It is difficult to measure the mechanical operation of bridges under torsion and it is generally wise to make measurements under loads that do not subject the deck to torsional stresses.

For bridges which are sensitive to thermal effects (prestressed concrete bridges, cable-supported bridges), the average temperature and the thermal gradient should be measured at various points on the structure in order to evaluate their effect and correct the measurements accordingly.

The deformation of secondary bearing structures (metal brackets) must be measured, separately from the strain occurring in the main structure. To limit interference of this type, the measurements on the secondary members should be performed near the bearings.

3 - Organization of the tests by the project manager

3.1 - The role of tests in bridge construction

In most cases, bridge testing is the last external monitoring action to be performed when a new bridge is built.

These tests can only be performed after a wearing course that protects the deck and its waterproofing structures has been laid, the capacity of the materials to withstand the test loads has been verified and the final adjustment of the bearings has been made.

In the case of structures or parts of structures that are made from concrete, the concrete must have attained a sufficient age at the date of testing. The tests must not begin before a minimum of 28 days have elapsed after the last concrete has been cast and must be conditional on the concrete achieving the strength values stated in the calculation notes.

The contract can stipulate that the contractor should make available a structure that is not yet finished to permit other works to be performed (for example earthworks). In this case article 43 of the CCAG applies.

Both before and after these structures are made available, the project manager and the contractor should conduct a joint inspection. Obviously, the structure should have been designed and built to withstand the effects of the anticipated loads.

If the contract stipulates that the tests are to be conducted a long time after the completion of works, acceptance of the bridge must be conditional on the subsequent performance of the tests laid down in the CCAP.

The contractor will draw up the hypothesis note, the calculation note, and the test programme. The other operations, such as the inspection of the completed structures, the recording of a failure to perform services specified in the contract, must, of course, be continued. In this case, the project manager will be responsible for conducting and interpreting the tests, in the presence of a representative of the contractor.

Except in an emergency, the client should not take possession of the bridge prior to its acceptance.

3.2 - The nature of the tests

The tests provide assessment information that enables the project manager to advise the client on whether or not it should accept the bridge.

The tests constitute an overall measurement of one or more behaviours of the structure in response to an external stress, enabling an assessment of the acceptability of the bridge with regard to is intended use, carrying road traffic. The interpretation of this measurement is difficult and great care is necessary as to how it is done.

3.3 - The actors engaged in the tests

Many actors, with various roles, are involved in conducting the tests. The involvement of the project manager in order to coordinate the different parties is therefore particularly important. To this end, the project manager should specify, by means of the specification for each commission, the role, tasks and missions of each party:

- the contractor who has won the contract,
- the contractor's design office
- the project manager's design office,
- the civil engineering test laboratory and/or the surveyor that is to make and exploit the measurements,
- the haulage companies which own the test vehicles,
- the body responsible for recording disorders before, during and after loading.
- the manager in charge of the weighing operations that enable the applied loads to be determined

It is helpful to use the organization given below as a basis. This organization is that used by the approach conventionally used by the Département Infrastructure Directorate (DDE). The requirements in question should be included in the contract):

- the contractor will perform the general organization, draw up the calculation notes, specify the test programme and interpret the tests. It will provide, amongst other things, the project manager with the access that is required to make inspections and measurement, and as well as the lorries or weights needed for the tests. The contractor will meet the costs arising from these services,
- the project manager will conduct external monitoring of the services provided by the contractor, draw up the reports on the condition of the bridges before and after loading, and measure the prescribed physical quantities, the measurements and inspections will generally be contracted out by the project manager. These tasks will be performed jointly with the contractor.

The tests should be conducted in the presence of the project manager (or a qualified representative of the project manager). These persons should monitor the conduct of the tests in real time and halt them in the event of an anomaly.

The analysis of the test results drawn up by the contractor should be formally validated by the contractor, that is to say approved with or without reservations.

	Contractor		Project manager		
	CE (1)	Contractor	Measurement	DO (2)	PM
Preliminary bridge inspection		X		X	V
Hypothesis note	X			PV	V
Calculation note	X			PV	V
Test programme		X			V
Test loads		X			V
Measurements			X		
Analysis of results	X		X	PV	V
Acceptance decision				X	V

Key:
X: Performance; V: Validation with certificate; PV: Proposal of validation
DO: Design office; PM: project manager

(1) Contractor's Design Office
(2) Project manager's Design office which is also able to performed detailed monitoring.

The client may also describe the reference state of the bridge during this pre-acceptance operation. Readers are reminded that any detectable defects which were not the object of reservations at the time of acceptance will be deemed to have been accepted by the client.

3.4 - The conduct of the tests

3.4.1 - The calculation note

3.4.1.1 - The hypothesis note

The contractor will provide the project manager with the hypothesis note in accordance with the requirements stated in Chapter 4. The project manager must return this hypothesis note approved and with any comments.

3.4.1.2 - The calculation note

The project manager must approve the calculation note, which is a condition for cessation of the interruption that is imposed before loading operations. The nature of this note is explained in Chapter 0.

3.4.2 - The test programme and the organization of loading operations

The contractor will suggest a loading programme that should describe all the essential aspects of bridge tests.

In particular, this document will explain:

- the general organization of the tests, with responsibilities explicitly stated,
- the order of the loading operations on the different parts of the bridge,
- the type of equipment to be used, both in terms of the vehicles and the measurement and communication devices,
- a plan for vehicle movements, in accordance with the calculation note, aims to optimize movements and the installation of measurement equipment,
- the geometric compatibility between optical measurement techniques and loading operations which may obstruct certain sightings,
- the way the position of loads is marked,
- if required, the measures to be implemented in order to stabilize thermal effects.

N.B. – Before the structure is loaded, the contractor will mark the position of the vehicles for the different loading cases. It is possible to develop a code using a number of stripes for the different loading cases and different colours for the type of vehicle, and indicate the part of the lorry (last rear axle). As the vehicles actually used are frequently slightly different from those defined in the calculation note, it is preferable for the position of the axle with the greatest load to be marked in order to remain close to the design hypotheses.

3.4.3 - The resources employed to conduct the measurements

The project manager must verify that the body conducting the civil engineering measurements has appropriate resources to deal with the problems posed and will meet the quality requirements stated in Chapter 0. In particular, it will verify:

- the field of use of the equipment, the metrological characteristics of the devices,
- their calibration
- the qualification of the staff using the measurement equipment,
- consistency between the organization of the measurement tasks and the loading operations: the reliability of the measurements, the time lapse between each measurement,
- rapid access to the values that enable the good operation of the structure to be checked in real time

It will also be verified that the body conducting the civil engineering tests genuinely possesses the ability to record the physical quantities that are measured on the structure and the parameters that are likely to influence the measurements: the temperature of the air and the structure, thermal gradient, water level, relative humidity, etc.

The recording of these parameters is extremely important as it means that measurements can be taken throughout the life of the bridge, to compare two states and evaluate the change in its behaviour over the course of time.

It should be noted that if it is not possible to demonstrate a degree of constancy in these parameters, it is preferable to conduct tests at moments or under conditions when variations are minimal, for example early in the morning, in cloudy weather, during a neap tide, in the absence of high winds, etc.

3.4.4 - Preliminary inspection of the structure

Prior to any loading activity, a detailed inspection of the bridge must be conducted by both parties in order for any defects to be noted, measured and quantified. This makes it possible to check if any changes occur during or after the loading tests.

The contractor who has won the contract for the works should be informed of the results of the preliminary inspection to be able to perform an inspection of its own and, when necessary, suggest strengthening measures.

The level of detail employed for this monitoring operation is that of a detailed bridge inspection conducted according to the principles laid down in Fascicle 2 of the Technical Guidelines for the Monitoring and Maintenance of Engineering Structures, concerning the conduct of monitoring.

It should be entrusted to a specialized body or a laboratory with staff who are trained and qualified in bridge inspection (**Figure 5**). In most cases the body that is responsible for external monitoring of works is selected because of its knowledge of the project. Traditionally, the laboratories of the Ministry of Public Works apply their know-how in order to perform this role and consequently may provide valuable assistance.

Figure 5: *Inspection using a temporary gangway*

This inspection should make it possible to assess the capacity of the bridge to withstand the tests. If the observed disorders reveal a threat to the structure it is necessary to stop the acceptance procedure and ask the contractor to analyze the disorders and propose repairs if necessary. If a repair is carried out, its effectiveness must be tested before the loading tests are conducted.

Finally, if the disorders do not threaten the stability and strength of the structure, the project manager can accept that they are not repaired before the tests. The project manager can then select specific instrumentation in order to monitor the development of the disorder (which is assumed to be reversible) under the effect of the test loads. In such a case it is appropriate to apply the loading in stages.

N.B. – Examples of disorders which are candidates for instrumentation include: cracks a few tenths of a millimetre wide in reinforced concrete structures, excessive deplanation of the web of a metal beam, a constructional defect leading to the generation of unbalanced forces, etc.

3.4.5 - Verification of the applied loads

Each lorry is required to have a weighing certificate (stating its total weight and weight per axle), which is dated on the same day as each phase of testing and on a weighing station that has been recently calibrated and checked (**Figure 6**). Generally a departure of 3 % with regard to the total mass is accepted.

Figure 6: *Weighing a lorry on scales*

In the case of tests that are conducted in heavy rain, the change in mass caused by the change in the water content of loads should be monitored.

The Highway Code must be obeyed to the letter at all times, in particular as regards the total permitted load.

The contractor must make sure that the real position of the axles is within 10 cm of the theoretical position, in both longitudinal and transverse directions.

Attention is drawn to the fact that the size of some loads is not always accurately known. Some loads can extend beyond the back of the vehicles and make it impossible to implement the planned arrangements. In this situation, the necessary adjustments are to be made to calculation note.

3.4.6 - Loading the bridge and measurements

Firstly, the body conducting the civil engineering tests must propose a testing programme in accordance with the requirements stated in section 0.
It is beneficial to ask this organization to find out about the climatic conditions that are forecast during the period it will be in action, particularly with regard to snow, wind, temperature and fog. Likewise, it is advisable to check the weather forecast the day before the tests in order to avoid unnecessary deployment.

Before the tests, the project manager must check that all the administrative permits (as regards traffic management, access to adjacent land in order to perform measurements, etc.) have been obtained, and that the communications equipment (for example radios) required for the various parties (general contractor, measurement technicians and surveyors) to communicate with each other is available and working.

The loading of bearings (**Figure 7**) enables their settlement to be obtained immediately. Such settlement is usually extremely small (of the order of a few tenths of millimetres). There is no other requirement apart from monitoring the settlement and measuring the level of the deck after the removal of the loads. If the settlement cannot at first sight be ignored, i.e. exceeds 0.5 cm (a value which varies according to the type of structure) it should have been evaluated in the calculation note for the bridge. The various surveying measurements after unloading of the structure (return to the empty state) can, insofar as they have been conducted in accordance with the conditions specified in fascicle 04 of the Technical Guidelines, constitute the Initial Reference Topometric State.

Figure 7: *Loading of a bearing*

The spans are to be loaded in the order specified in the loading programme. Safety guidelines prohibit the simultaneous movement of more than one vehicle on the bridge. This rule should also be applied at the end of the tests when the lorries are removed from the bridge.

The organization conducting the civil engineering tests must check at all times that the significant physical value measured under the loading case in question does not exceed 1.5 times the forecast value, to ensure there is no threat to the bridge. If this limit is exceeded the tests must be halted. The measurements made on the other parts of the deck can be adjusted on the basis of the measured settlement of the bearings. Warning levels must be stated for any additional instrumentation that is installed to evaluate a certain disorder or a specific behaviour.

3.4.7 - Inspection after the tests

The aim of this is to observe the state of the bridge after the tests and compare it to the initial state recorded before them. These observations must be noted on the document used for the preliminary inspection, and differentiated from the initial observations.

This inspection can beneficially be conducted as described in the Technical Guidelines, in order to constitute the Initial Detailed Inspection (IDI). In this case, it must obviously be conducted jointly with the contractor.

It must be borne in mind that the deadlines that apply to the acceptance certificate and covered by article 41 of the CCAG do not always allow all the operations prior to acceptance to performed, particularly if the IDI is included. This is frequently the case for non-standard bridges. Two solutions can be envisaged in the CCAP:

- including a longer time limit in the contract,
- making acceptance conditional on the results of the IDI.

3.4.8 - Analysis of results and validation after the tests

The body conducting the civil engineering tests will make a report for the project manager about the measurements made during the tests which will include:

- a list of the real loads used and their positions,
- a statement and analysis of the measurement conditions,
- a list of the expected values and the acceptable departures from them with reference to uncertainties concerning the models and the values,
- a list of the uncertainties that affect the measurements,
- a comparison between the results that were measured and processed and the computed values.

On the basis of this report, the contractor’s design office will draw up a results analysis document including at least the following sections:

- a list of the hypotheses,
- (perhaps) a reworking of the calculations,
- interpretation of the differences, when applicable,
- conclusions regarding the ability of the structure to perform its functions and its durability,
- information about the appropriate monitoring regime for the structure and about any permanent or temporary additional instrumentation

With assistance from its design office, the project manager will analyze the contractor’s report and reach a conclusion concerning future action as regards the bridge acceptance process.

3.4.9 - The case of certain bridges

The principles described below refer to the majority of bridges including principal structures. The tests that are conducted after bridge repairs or strengthening must be adapted to each specific case.

However, for some particularly simple and robust structures that are constructed in accordance with the SETRA standard design documents, such as small closed or open frame reinforced concrete bridges (a span of less than 10m), simpler procedures may be applied (**Figure 8** and Chapter 0).

Figure 8: *Loading test on a short span bridge*

4 - Calculation note for tests and analysis of results

4.1 - Design hypotheses for the tests

The calculations for the bridge under test loads do not aim to check the ultimate strength of the structure but to test that it functions correctly. Consequently, the hypotheses used for the calculation should not be conservative but as realistic as possible, when physical measurements are necessary. Likewise, modelling of the stiffness of the structure should be compatible with the calculated deformations under test loads. Valuable information can be found in the Eurocodes. The following, in particular, should be considered:

- the shear stress deformation in the beams,
- the role played by certain equipment with regard to the stiffness of the structure (for example BN1 and BN2 type barriers, RC cornice, RC kerb restraint),
- the real behaviour law of the materials derived from tests on specimens,
- the stiffness of the bearings, in particular with regard to rotation,
- the skewness of the structures,
- the curvature of the structures,
- cracking of reinforced concrete sections, in particular cracking of composite bridge slabs on supports and the reduction in torsion inertia as a consequence of cracking,
- the participating width of the slab and the supported slabs,
- the probable value of the prestressing force (using the results of transmission coefficient measurements) for partially prestressed bridges,
- the real geometry of the bridge, if problems during construction have led to modifications.

A full calculation for the bridge is required, based on realistic hypotheses that permit its probable state to be forecast. An uncertainty of +10% and –20 % is generally accepted as regards the likely values of physical quantities (deformation, etc.), except when specifically justified by the design office. For each loading operation, the most significant physical quantity will be defined and used as the principal characteristic indicator of the good operation of the structure. The design office will determine the limit value of this physical quantity and the tests will be halted if this is attained. In the absence of specific analysis, the figure of 1.5 times the nominal design value should be taken.

N.B. – The stiffness provided by superstructures can become very great in the case of small spans. Concrete safety barriers (BN1, BN2, GBA…) are responsible for a considerable amount of stiffness which is quite difficult to model as a result of joints, cracking and shear lag. The contractor will provide the project manager with the hypothesis note which the latter will approve with any necessary comments.

4.2 - Calculation note for the tests

This calculation note, which must be drafted by the contractor, will include

- a brief description of the characteristics of the structure,
- a description of the hypotheses that have been made,
- a description of the different loading cases,
- the nature and theoretical value of the measurements to be made in each case.

The kinematics of lorry movements should be planned so effects greater than the test loads are not generated in any principal section.

4.2.1.1 - Before the tests

The following are required:

- calculation of the likely state of the bridge on the test day under real permanent loads,
- calculation of the effects of frequent characteristic traffic loads,
- the impact on the structure of natural factors such as temperature, thermal gradient (the temperature differences between different parts of the bridge), in order to be able to interpret in-situ measurements.
- the selection of test loads and their simulation using lorries hired by the contractor. The effect of these loads will be calculated without weightings, taking account of the real characteristics of the lorries (axle loads, wheelbase, etc.),
- statement of the acceptable uncertainty with regard to the weight and positions of the loading convoys,
- statement of the successive positions (longitudinal and transverse) of the lorries and the principal sections to be tested in each position,
- quantification of the physical quantities that are representative of the mechanical operation of the bridge during the tests and tracing the pseudo influence lines if these are required,
- uncertainties as regards the calculation of physical quantities and as regards the measurements should be made clear,
- any necessary dynamic calculations, with an analysis of their accuracy,
- determination of the settlement of bearings under traffic loads, if this is large (in excess of 1 or 5 mm depending on the type of structure).

4.2.1.2 - After the tests

The following are required:

- verification of the experimental and theoretical results, and explanation of any divergences from them,
- if necessary, additional investigations based on more realistic models.

This last point relates in particular to local loading tests when the measured values are unsatisfactory but nevertheless indicate that the tested members are functioning in a uniform manner. If a member appears to be unsatisfactory as the result of poor manufacturing, the contractor must suggest a monitoring method to the project manager which can guarantee that all similar members will be manufactured correctly. In practice, it frequently becomes necessary to generalize measurements or tests in order to detect all the defective members. In addition, the contractor must propose methods for bringing the structure or the part of the structure up to standard.

4.3 - Analysis of results

The analysis of results should be conducted with a view to revealing any mechanical malfunctions on the basis of the reports drawn up before, during and after testing. The calculations must therefore consider not only the real weights and positions of the lorries, but also the influence of climatic conditions.

The test results are satisfactory when the measured values, taking account of measurement uncertainties, are close enough to the calculated values (between 1.1 times and 0.8 times the probable values). If this requirement is not met, the results must be examined critically in order to explain the anomalies: non-linearity of behaviour, abnormal changes in deflection in a principal section etc.

A new calculation must be performed to establish the range of theoretical values to be checked on the bridge, on the basis of realistic high and low hypotheses about significant physical quantities. There is generally no need to begin any or all of the tests. If any or all of the tests need to be repeated, the associated costs are to be met by the contractor

5 - Taking of measurements and presentation of results

5.1 - Data required for effective instrumentation

5.1.1 - Geometrical and topographical characteristics

Generally, the nature and geometry of the bridge (whether it crosses a river, height under beam, etc.) and, more particularly, the characteristics of the deck (length, width, thickness, skewness, curvature, distance between bearings) the nature of the bearings (height and freedom of movement) will influence the selection and positioning of measurement equipment.

It is usually possible to answer the questions that arise if a top view, a cross section or a longitudinal section are provided, at least in the case of standard structures. A specific visit is required when the bridge crosses a large gap or river, in urban areas or port zones, in order to decide on the choice and positioning of measurement equipment. This is also often the case for non-standard bridges (**Figure 9**).

Figure 9: *Loading test on a bow-string bridge*

5.1.2 - Measurement programme

The measurement programme will be drawn up on by the body conducting the civil engineering measurements. It will lay down the number and type of the measurement devices, their positioning, the number of staff required to perform the tests and their qualifications. It will include at least the following operations:

- the positions of the loads and measurement points,
- a detailed inspection by both parties before any loading operations,
- preliminary levelling,
- verification of the characteristics of the loading devices, verification of the weighing certificates and possibly the scales used for weighing,
- the loading of bearings and level measurements,
- the loads mentioned in the calculation note (details of the sequence of cases and the corresponding measurements and observations),
- conduct of the detailed inspection, or the initial detailed inspection, after the removal of the loads, by qualified inspectors, and measurement of the reference levels

The cost of these operations is to be met by the design office with responsibility for the measurements. The project manager may ask another subcontractor to perform the detailed inspections before and after loading.

5.2 - Possible types of measurement

The annex contains descriptions of the various devices described.

5.2.1 - General comments concerning metrological characteristics (based on NF X07-001 - December 94)

The terms used in metrology are defined thus:

- the limits of the measurement range: minimum and maximum measurable values,
- measurement range: difference between the minimum and maximum measurable values,
- resolution: the smallest measurable difference,
- measurement uncertainty: value that characterizes the dispersion of results

5.2.2 - Displacement measurements

These are the most common measurements during loading tests. Vertical displacement measurements are the most frequent, as they generally reveal the mechanical performance of the bridge as a whole and are easy to perform.

They provide a way of monitoring deflections under loads, transverse deformations of the deck and any settlement of bearings. Occasionally, it is also necessary to monitor horizontal displacements in the case of high pier heads, the towers of cable-stayed or suspension bridges, the heads of inclined legs or counter struts on the decks of portal bridges.

The following devices may be used for measuring displacements:

- mechanical fleximeters of the type made by “Jules Richard Instruments”: the displacement of the bridge is transmitted by an invar wire fixed vertically under the deck and held taught. The fleximeter traces the displacement on a recording drum by means of a set of lever arms,
- displacement sensors: as with mechanical displacement gauges, the displacement is transmitted by an invar wire; these sensors may also be placed on a rigid support near the deck
- laser flexigraphs: the displacement of the bridge in relation to a reference laser beam is monitored (thermal effects must be considered),
- surveying equipment: the displacement of the structure is measured using a high-precision level and an invar rod,
- motorized theodolite: this levelling device automatically monitors the displacement of the bridge using targets whose initial coordinates are known.

5.2.3 - Deformation measurements

Deformation measurements are rarely made during the tests because displacement tests are more comprehensive and easier to exploit. However, they are indispensable as a means of finding out the local behaviour of the most stressed sections or the sections with the highest stress concentrations. The curvemeter provides a semi-comprehensive measurement of the behaviour of concrete beams by detecting for example cracking that occurs under test loads.

The following devices may be used for deformation measurements:

- electrical gauges: the deformation of the surface to which they are attached (steel or concrete) modifies their electrical resistance,
- vibrating wires: these are placed inside the formwork before the concrete is cast and then monitor the deformation of the concrete which alters their resonance frequency. They can also be attached to the facing
- strain gauges: the deformation of the support to which the strain gauges are attached is measured by mechanical or electrical techniques. These gauges can have longer measurement bases than electrical gauges (their lengths can be varied between 10 and 50 cm according to needs),
- optical fibres: the signal transmitted by the optical fibres is modified by the deformation of the support to which they are attached,
- curvemeters: the curvature generated by an excessive load can be measured on the basis of the relative rotation of two adjacent sections.

5.2.4 - Rotation measurements

Currently, in most cases, rotation measurements are used to monitor the rotation of the sections in which other measurement equipment is installed (laser sources for example). They are mainly used in the areas around supports, on high bearings, near arch fixing restraints, etc. The equipment used to measure rotation consists of levels or inclinometers which measure the rotation of the base on which they are placed.

It can also be useful to measure the rotation of certain bearings (pot bearings, metal bearings) to check they are functioning correctly.

5.2.5 - Vibration measurements

Vibration measurements are currently rarely used during testing. Essentially, they provide a means of measuring the natural frequencies of the bridge. However, with our current state of knowledge, the results from this type of measurement do not provide a precise enough description of the behaviour of materials or structures. This situation may well change, in particular in the case of structures that are flexible or sensitive to dynamic phenomena: it is for this reason that these measurements are described briefly.

The principal sensors that can be used for vibration measurements are as follows:

- accelerometers: when used with a charge amplifier these output a voltage that is proportional to the acceleration,
- geophones: these output a voltage that is proportional to the speed.

5.2.6 - Weighing operations

The weighing operations in question do not involve the structures, but the devices used to load them. Generally, lorries that have been weighed beforehand on weighbridges are used.

The attention of participants should be drawn to the possible influence of irregularities in the wearing course on the distribution of loads.

In some circumstances (when tests last for more than half a day, when moist aggregate is used, during rain, etc.) it may be advisable to re-weigh the lorries after the tests.

5.3 - Presentation of results

The loading tests and the qualitative and quantitative observations made during them will be presented in a report drafted by the body responsible for conducting civil engineering tests which makes the measurements. In particular the report will describe:

- the loading programme conducted (the sequence of different loads, times, measurements, observations, etc.),
- the characteristics of the loads (in the case of lorries, the gross weight, axle weight and distance between axles),
- the measurement equipment used,
- the measured values with their uncertainty) compared with the corresponding theoretical values
- the observations,
- the conditions under which the tests took place (temperature, sunshine, etc.) and their mechanical impact on the bridge (thermal gradient, etc.).

The various measurement devices are described in Annex 2 of this document.

6 - Test programmes for standard bridges

In most cases, the bridges in question are standard types for which the SETRA has published a variety of methodological documents or design guides, or structures of a type approved by the SETRA. These bridges, made of reinforced concrete or prestressed concrete or of three types:

- rigid frame bridges and frames,
- slab bridges or wide rib cast in-situ bridges,
- beam bridges.

The operations to be conducted for each of these types have many similarities. However, differences exist, related to the type of material (reinforced or prestressed concrete) and the mechanical operation of the structure (continuous or independent spans).

For these standard bridges, the shear deformations can quite rightly be assumed to be negligible, which explains why measurements mainly involve the effect of bending stresses. The predominant stresses to be considered are therefore the moments in the span and, in the case of continuous structures, the moments above the bearings. For highly skewed slab bridges, the deflections at the free edges are however sensitive to the shear deformations which arise in them. In view of these phenomena, the deformations measured on the free edges can only be compared with those which result from a reliable calculation.

The relevant measurements essentially involve deflection in the span. Generally, the rotations of the sections above bearings are not measured.

During the first loading/unloading cycle of the bearings, measurements must be made of the settlement of the bearings. These will be used when producing the description of the reference state of the bridge. Settlement can also be caused by the foundation soil: this occurs in particular at the beginning of the life of the structure. It may be of value, for small bridges built on shallow footings, to measure the settlement of the bearings under the first load.

In the case of straight or slightly skew bridges it is still uncommon to measure reactions at support. However, in the case of bridges that are very curved (with a radius of less than five times the span) and/or highly skewed (in which case there is a risk of lifting at the angles) weighing tests and displacement tests may be performed, either using a comparator or by levelling. It should be noted that that, depending on the configurations, this lifting under test loads may occur in the case of either obtuse or acute angles. For these structures, a preliminary inspection of the condition of the bearings (to detect any distortion and verify the quality of contact with the deck) is particularly useful.

It most cases it is sufficient to install the measurement points along the axis of the bridge. However, in the case of particularly wide bridges (say in excess of 15 metres) or highly skewed bridges (angle of skew less than 50 centesimal degrees), it may be advisable to install additional measurement points along the central line of a beam which is near the free edges. In the case of beam bridges it is normal practice to instrument one line of beams in the centre and one at the edge.

6.1 - Rigid frame bridges and frames

6.1.1 - Preliminary inspection of the bridge

The defects and disorders that are likely to be observed in rigid frame bridges and frames are common to most reinforced concrete structures. They can be caused either by design or construction, but occasionally the materials are responsible.

When the tests are conducted, defects in concrete casting, abnormal cracking and geometrical irregularities can be observed. These defects are usually due to errors in the positioning of centring and formwork, settlement under the weight of the fresh concrete, inadequate “secondary” reinforcement, plastic shrinkage of the concrete, etc.

The majority of the problems are nevertheless linked to unsatisfactory backfilling which can subject the structure to unexpected pressures. Further details can be found in Chapter 5 of the Design Guide for rigid frame bridges and frames (Guide de conception des ponts-cadres et portiques) and the Technical Guidelines for the Monitoring and Maintenance of Engineering Structures.

N.B. – For double frames and multiple rigid frame bridges, the same procedures are used as for the rigid frame bridges and frames described above.

2.1.2 - Hypothesis note

As has been stated in section 4.2 [do they mean 4.1?] of this document, it is important to make realistic hypotheses when selecting the parameters for calculating stresses and deflections. There is a degree of uncertainty attached to each of the physical quantities so that the probable calculated deflection in fact lies within a certain range of values. In the case of reinforced concrete structures the parameters involved are:

- t he mechanical characteristics of the sections (inertia),
- the elastic modulus of the concrete, which must be evaluated on the basis of tests on specimens and not on the basis of the theoretical design strength,
- the characteristics of the lorries used to perform the tests

In the case of rigid frame bridges and frames the characteristics of the soil and the quality of backfilling are added to these.

6.1.3 - Calculation note

The calculation note will give the values for the stresses and deflection at the centre of the head beam under the real lorries used for the tests.

6.1.4 - Loading programme

The position for the lorries which produces the most unfavourable effect should be marked on the pavement. The lorries should move one at a time to take up their positions. Normally it is sufficient for the loading convoy to be positioned on the axis of the bridge (**Figure 10**).

Figure 10: *Central loading of a multiple span frame*

6.1.5 - Interpretation

The measured deflections must fall within a range derived from the uncertainties described in the hypothesis note. This provides a straightforward indicator of the good operation of the bridge.

6.1.6 - Possibility of simpler tests

For small span bridges, for example closed frame reinforced concrete bridges less than 10 metres wide, it is possible just to observe the effect of the passage of lorries without measuring the deflections. The same applies to structures covered by a large depth of fill (at least 1.5 metres or more than a quarter of the span), as the backfilling and compaction processes are more critical than the test loads. In this case it is important to pay particular attention to the staging of construction and make a clear separation between deformation and settlement.

6.2 - Slab bridges, wide rib bridges

6.2.1 - Preliminary inspection of the bridge

The defects and disorders that are likely to be observed in slab bridges are few in relation to the total number of such bridges.

This is because the massive structures in question are relatively easy to design and construct. At the time of the tests, defects can be caused by the following:

- inadequate passive reinforcement,
- cracking in near the ends of the deck (spread of prestressing stresses),
- longitudinal cracks,
- transverse cracks (moment peaks, thermal gradient, differential shrinkage),
- poor positioning of prestressing tendons,
- defective concrete casting,
- distortion of bearings, poor contact with the deck, particularly in the case of highly skewed slab bridges.

N.B. - Further details can be found in Chapter 5 of the Design Guide for Slab Bridges (Guide de conception des ponts-dalles), and in the Technical Guidelines for the Monitoring and Maintenance of Engineering Structures.

6.2.2 - An example of a loading programme

This example involves a relatively large structure, which justifies a particularly comprehensive and detailed test programme. This programme could be simplified for smaller structures. The bridge in question is a bridge with two prestressed ribs and four spans (of 27.00 m; 38.00 m; 27.00 m and 23.00 m). The bridge is straight and has a loadable width of 9.30 m (3 traffic lanes).

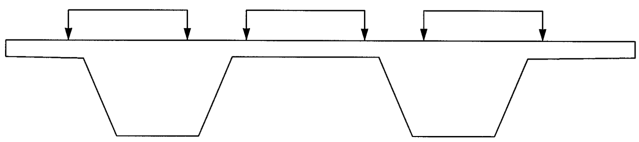

Diagram 1: **Cross-section of the bridge**

6.2.2.1 - Loading programme

The tests in this case require 6 lorries (2 x 3) each weighing 26 t (front axle = 5 t; rear axles = 2 x 10.5 t)

a) Preliminary loading of bearings

The lorries will be placed over each line of bearings in turn. It must not be forgotten that only one lorry should be moved at a time, the others remaining stationary. The observed settlements will be compared with the forecast settlements.

b) Description of the loading cases

The positions will be sought which generate the desired stresses in the four spans and on the three intermediate bearings P2, P3, P4. In most cases, loading is midspan and performed by three lines of two lorries.

- ***Loading operation 1***

This relates to the positive moment in span 1 under the action of three lines of two lorries positioned on span 1.

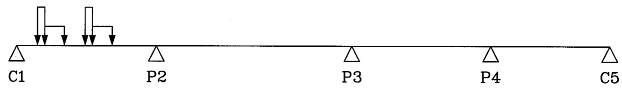

Diagram 2: *Loading of span 1*

- ***Loading operation 2***

This relates simultaneously to the positive moment in span 2 and the negative moment on bearing P3. It involves three lines of two lorries positioned on span 2.

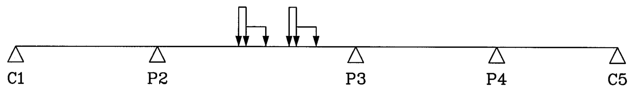

Diagram 3: *Loading of span 2*

- ***Loading operation 3***

This relates to the positive moment in span 3 generated by three lines of two lorries positioned on span 3.

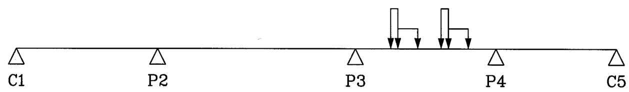

Diagram 4: *Loading of span 3*

- ***Loading operation 4***

This relates to the negative moment on bearing P4 which is obtained by positioning:

- the first row of three lorries on span 4,
- the second row of three lorries on span 3.

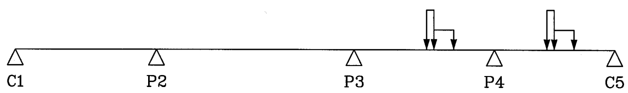

Diagram 5: *Loading for the negative moment on bearing P4*

- ***Loading operation 5***

This relates to the positive moment in span 4 under the action of three lines of two lorries positioned on span 4.

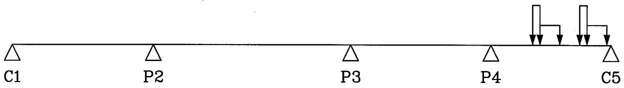

Diagram 6: *Loading of span 4*

In this specific case, it is not possible to achieve the desired negative moment on bearing P2 by midspan loading applied by three lines of two lorries. To avoid the need for additional lorries, off-axis loading is performed, on the left side then the right side. This off axis loading makes it possible to impose adequate loads on each rib in turn.

- ***Loading operation 6***

This relates to the negative moment on bearing P2 for the right rib. It is obtained by applying an off-axis load to the right side of the bridge:

- two rows of two lorries on span 2,
- one row of two lorries on span 1.

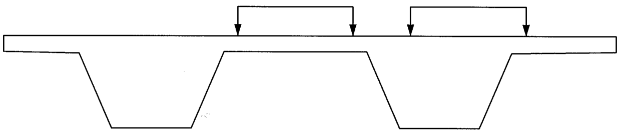

Diagram 7 *Transverse position for the negative moment on P2 – right rib*

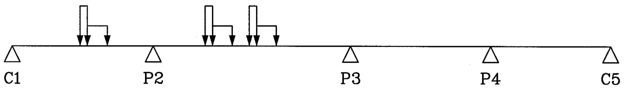

Diagram 8: *Longitudinal position for the negative moment on P2 – right rib*

- ***Loading operation 7***

This involves the negative moment on bearing P2, for the left rib. It is obtained by applying an off-axis load to the let side of the bridge:

- two rows of two lorries on span 2,
- one row of two lorries on span 1.

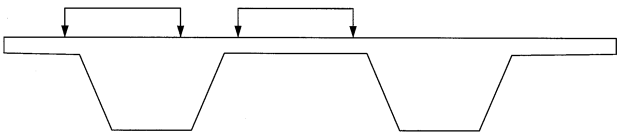

Diagram 9: *Transverse position for the negative moment on P2 – left rib*

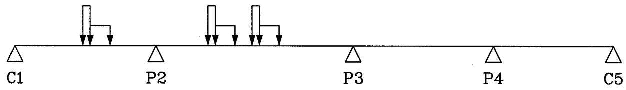

Diagram 10: *Longitudinal position for the negative moment on P2 – left rib*

6.2.2.2 - Instrumentation

The principal measurements are of deflection.

For this purpose, the benchmarks are to be placed under the intrados of each rib, in line with the decisive sections on each span.

There are other possibilities, for example the use of a flexigraph or strain gauges.

6.3 - Paved beam bridges

Prestressed concrete beam bridges include postensioned prestressed girder bridges and pretensioned prestressed girder bridges.

Multiple span postensioned prestressed girder bridges consist of a succession of independent spans; it is increasingly common to make pretensioned prestressed girder bridges continuous by means of a reinforced concrete junction on the intermediate bearings.

In the case of continuous span pretensioned prestressed girder bridges, the conduct of deflection measurements on the different spans provides an opportunity for a posteriori testing of the hypothesis that the deck is continuous over the pier which is applied during design of the structure. However, only major losses of continuity can be detected.

6.3.1 - Preliminary inspection of the bridge

The defects and disorders that are linked to construction are in most cases due to poor concrete casting in zones where there is a high density of reinforcement. Tensioning prestressing cables when the concrete is too young can also cause excessive stresses in the concrete leading to cracking. Poorly performed handling operations can lead to the spalling of edges and localized pop-outs. Such disorders must be identified and repaired before the day of testing.

N.B. - Further details can be found in Chapter 5 of the Design Guide for Precast Postensioned Slab Bridges (Guide de conception des ponts à poutres préfabriquées précontraintes par post-tension), and the Technical Guidelines for the Monitoring and Maintenance of Engineering Structures disseminated by SETRA.

6.3.2 - Hypothesis note

The following physical quantities are used when calculating the moments and deflections:

- the mechanical characteristics of the sections (inertia),
- the modulus of the concretes, which must be assessed on the basis of results measured on specimens and not on the basis of the theoretical design strengths. *It should be noted that the concrete in the beams and the slab may differ, which is an additional source of uncertainty,*
- the characteristics of the lorries used for the tests.

6.3.3 - Calculation note

The calculation note presents the results for the stresses and the deflections, at one quarter, half and three-quarters of the span for each instrumented beam.

6.3.4 - Loading programme

It is generally considered sufficient to test a central beam and one edge beam on each span. It is of course possible to go beyond this in order to investigate the behaviour of a given beam. Two transverse positions are therefore adopted for the group of lorries:

- a position that is on the axis of the structure, which causes maximum deflection in the central beam,
- an off-axis position, on the side of the edge beam whose maximum deflection is to be measured.

7 - Specific features of non-standard bridges

These are principally bridges one of whose spans exceeds 40 m. Some non-standard bridges consist of smaller bridges with unusual forms whose functioning is more complex. Project managers generally classify these structures according to the principal material used in their construction:

- prestressed concrete bridges,
- metal bridges,
- composite concrete and steel bridges,
- reinforced concrete bridges (rarely used for spans this long),
- wooden bridges (very rarely used for spans this long).

For the purposes of testing it is preferable to classify them with reference to their general mechanical operation. So-called conventional bridges, whose decks rest on rigid supports, are thus distinguished from complex bridges whose decks are supported by an elastic structure such as suspension cables or an arch.

7.1 - Decks that rest on rigid supports

For these bridges, the deck plays the role of a girder placed between two supports and is principally subjected to simple bending as a consequence of traffic loads. The deck bends under these loads and the significant physical quantity to be measured is the vertical deflection. The deflections in the middle of the span (or at the point of maximum deflection in the case of the edge spans) are often significant and therefore easily measurable. Care must be taken to measure settlement over the bearings at the same time in order to correct the deflections measured in the spans. The tests result in systematic testing of all the principal sections of the structure, i.e., at least the sections above the bearings and the sections with the largest deflexion in spans.

When the bridge consists of a large number of virtually identical spans, the tests on the sections around the supports can be carried out on just a few bearings. However, the test loads must still be applied to the middle of each span.

7.1.1 - Torsionally rigid and transversally indeformable decks

These structures have an indeformable cross-section which undergoes an overall vertical displacement and a minor overall rotation.

Most large bridges fall into this category:

- launched prestressed concrete box beam bridges,
- cantilever constructed prestressed concrete box beam bridges,
- orthotropic slab metal box beam bridges,
- steel and concrete composite box beam bridges.

For large bridges, it is often difficult to gain access to the intrados. In some cases one possibility may be to take measurements inside the box beam. Because of the rigid transverse behaviour, it is acceptable to place the benchmarks at the edge of the extrados beyond the carriageway. The torsional rotation of the deck can be obtained either from the difference between the deflections on the two edges or measured directly with an inclinometer. It should be noted that a local inclinometer measurement may include slight transverse deformations and be less close to the average rotation.

For each principal section, the test load is generally located midspan and distributed over the different lanes. Some off-axis loading operations will enable the structure to be subjected to torsional stresses.

7.1.2 - Torsionally flexible and transversally rigid decks

These are paved beam bridges whose beams are connected either by regularly spaced cross beams or by highly rigid cross girders. This category of bridge essentially consists of two-beam concrete and steel composite bridges. As a result of the high transverse rigidity, the sections are practically indeformable in this plane, but considerable torsional rotation occurs. This generally means that it is necessary to conduct both midspan and off-axis loading on each principal section. In this case testing concentrates on the deflections of the two beams rather than the edges.

7.1.3 - Transversally deformable decks

These are paved beam bridges whose beams are connected either by the slab or by light cross beams. This category includes composite concrete and steel frame bridges consisting of a small number of box beams or beams (≥ 3), wide rib decks and some postensioned prestressed girder decks. The sections are no longer indeformable and each beam functions slightly independently from the others. In this case the deflection of each beam should be tested. When the beams are identical it is acceptable to test only the central beam and one edge beam. The tests should include:

- loading of the span intended to validate the distribution of traffic loads between the different beams by measuring the deflections on each beam,
- a loading procedure intended to test the principal sections of each beam, concentrating the heavy loads in one or two lines above the beam.

7.1.4 - Curved and skew bridges

Curvature and skew create large torsional moments in the structure, even when the traffic loading is on the axis of the bridge, and transverse deformation is therefore greater than in the case of a straight bridge. The deflection should be measured at points on the two edges of the bridge.

7.2 - Complex bridges

In these bridges the deck generally has elastic supports, sometimes in considerable numbers (suspension cables) and/or is subjected to combined bending and axial stresses under traffic loads. The number of measurement points per span must therefore be increased and the longitudinal displacement of the deck must also be measured. The test loads must be adapted to the specific forms of the influence lines of the moments on the bearings or in the span.

For example, in the case of an arch bridge, the maximum deformations will be obtained by loading one half of the structure between the abutment and the arch centre.

For decks that are supported by cables, it is often useful to displace a convoy consisting of one or two lorries on each lane.

In the case of cable-stayed bridges, the deflection of the deck is to be measured as well as the longitudinal displacement of the towers and the deck (**Figure 11**). For example, the measurement points on the principal span may be placed 25 metres apart with a minimum requirement of every quarter of the span. When possible, it is also of interest to measure variations in the tension of stay cables (load cells, strain gauges, vibration frequency).

Figure 11: *Test loads on a cable-stayed bridge*

In general, test loads that are fairly spread out are required in order to apply flexural stresses to the towers (edge spans and at least half of the main span as well) as more concentrated test loads in order to apply flexural stresses to the stay cables and the deck in the main cable-stayed span. The latter loading operations can frequently involve a convoy of constant geometry which is displaced along the entire length of the bridge in the vicinity of the sections to which stresses are to be applied. In the case of flexible decks, this convoy is made up of 1 or 2 lorries on each lane; for stiffer decks, the loaded length is increased in order to obtain the desired level of stress (for example to one quarter of the main span).

As these structures are generally very large or supported by two rows of stay cables, off-axis loading should also be performed.

For suspension bridges with a mobile saddle, its displacement with respect to the top of the tower should be measured.

In the case of arch bridges, the deflection of the deck and the arch are to be measured, as well as the rotation of the supporting structure and the longitudinal displacements. The measurement points on the deck and the arch should be positioned above the small piers and between them. Loads can be applied to each span of the deck as well as more general loads to apply stresses to the arch. In the case of the arch, tests may include a test convoy that simulates loading of a half-span of the bridge and that is displaced by one quarter of the span of the arch (***Figure 12***).

Figure 12: *Loading of an arch bridge.*

These structures are frequently instrumented to make it possible to monitor the rotation of the supporting structure (using an inclinometer) and the flexural moment during jacking of a section at the base of the arch, and obviously this existing instrumentation should be put to use.

For bow string bridges, as for any arch bridge, the tests must include the testing, as a minimum, of the two half spans (loading from an abutment to the section with the arch centre), then loading of the entire span (***Figure 13***). As above, it is also of value to displace a convoy that consists of one or two lorries in each line. The measurement points should be positioned along the deck and on the arch at least every quarter of the span.

Figure 13: *Measurement of deflections during tests on a bow string.*

In the case of portal bridges, measurements will involve the deflection of the deck, the longitudinal displacement of the deck, and the rotation at the junction between the deck and the inclined leg and at the base of the inclined leg. The measurement points for the deflection of the deck will be located at its junction with the inclined leg and at least every quarter of the span.

For extremely flexible structures which are sensitive to dynamic effects, the additional measurements to be performed in order to quantify the dynamic behaviour of the structure under the action of wind and pedestrians are described in Chapter 2. If the measured damping is much lower than forecast, some calculations may have to be repeated and dampers may have to be installed.

N.B. – When measurement devices have been installed in the structure for the purposes of monitoring during construction (strain gauges, inclinometers, etc.), data from them may be used during the tests. If the measurement positions used in the course of geometric tests do not coincide with that already in use, it is important to establish a correspondence between the two.

For complex structures it is generally appropriate to record the movement of the deck during a thermal cycle in the days before or after the loading tests as a result of their high sensitivity to thermal effects.

For such complex structures, it is worth considering what permanent measurement systems can be installed: anemometers, accelerometers, temperature probes, vibrating wires, etc.

7.3 - Local behaviour

Specific parts of the structure may be instrumented in order to check its local behaviour under relatively concentrated loads (one or two lorries). For example:

- a complex connection node such as the junction between an inclined leg and the deck,
- a metal bracket that extends a cross girder under the cantilevers,
- a metal or concrete bracket that supports a cantilevered part of the structure,
- rotations over the abutment of the beams of a highly skewed composite bridge, caused by the bending of the cross member above the bearing;
- local bending of orthotropic slabs (using strain gauges).

It is also possible to use the tests as an opportunity to measure the stiffness of part of the structure when this is not precisely known and has a major influence on stresses.

In the case of some composite structures which are subjected to particularly high fatigue stresses (motorway bridges for example) it is possible to measure fatigue deformations resulting from the passage of a lorry using gauges that are attached to the metal flanges. In this case, testing is performed mid-span by fitting at least three gauges to the lower flange in order to be able to compute a mean nominal stress value.

7.4 - The measurement of reactions at support

For some bridges, it may be appropriate to measure reactions at support under permanent loads. These measurements are usually made over the abutments, where the reactions at support are low (**Figure 14**). This involves mainly the following types of structure:

- prestressed concrete bridges,
- highly curved or highly skewed bridges with a poor equilibrium between the edge span and the adjacent span.

Figure 14: *Apparatus for measuring reactions at support.*

In view of the great effect of temperature variations (thermal gradients) on the measurement results, the measurements should take place within a period of roughly 24 hours. The thermal gradient must be measured at the same time so it is possible to correct the measurements of the reaction at support

8 - Annex 1

Model Clauses for the CCTP

8.1 - Structure for which no deformation measurement is required [1]

The structure in question is subjected to loading tests without any deflection measurements.

8.1.1 - The objectives of the tests

The objectives of these tests are as follows:

- to assure the client that the delivered structure is fully capable of carrying the test loads, and thus perform its function in terms of bearing capacity,
- constitute one of the elements of the description of the reference state of the structure.

8.1.2 - Organization of the tests

The contractor will be responsible for the general organization, drawing up the calculation notes, designing the test programme, and interpreting the tests. In addition, the contractor will provide the project manager with the necessary access to the structure in order for the staff responsible for inspections and testing to be able to perform their tasks, and also provide the lorries or weights that are required for the tests. The costs for these services are to be borne by the contractor.

The costs of inspections and level taking are to be met by the project manager. These operations are conducted jointly with the contractor. The contractor will direct the tests, the interpretation of which will be submitted to the project manager for approval. [As a derogation from Fascicle 61 title II] [2], the concrete may be less than 90 days old when the tests are performed. The minimum time since the last concrete was cast is one month, on condition the concrete strength values given in the calculation notes are obtained.

8.1.3 - Test loads

The structure will be subjected to general static loads which generate effects that are between those of frequent traffic loads and three-quarters of the effects of the characteristic traffic loads defined in Eurocode EN 1991-2, without, however, being less than the effects of a load of 2.5 kN/m^2 evenly distributed over the pavement.

The test loads must apply stresses to all the members in the structure. In practice, in this context it is the section in the middle of the span which is of interest.

Stationary test vehicles are to be placed on the carriageway. These may be moved close to each other either longitudinally or transversally, irrespective of the lane divisions on the carriageway.

Dynamic effects will be monitored qualitatively by performing simplified tests under moving loads. A number of vehicles equal to the number of lanes will be selected from among those used for the static loading tests, giving preference to those with the heaviest axles. These vehicles will be positioned side by side facing the same direction and will be moved from one end of the bridge to the other at a safe speed.

[1] Closed frame reinforced concrete bridges less than 10 metres in length or covered by a large depth of fill (at least 1.5 metres and more than a quarter of the span),

[2] Fascicle 61 Heading II must be applied pending a national standard for tests

8.1.4 - Calculation note

[Two months] (3) before the scheduled date of the tests, the contractor will draw up the calculation note which will include:

- a hypothesis note,
- the calculated probable state of the structure on the day of the tests under the effect of permanent loads,
- the calculated effects of the frequent characteristic loads,
- the selected test loads,
- the calculated (unweighted) effects of these loads, with reference to the real characteristics of the intended lorries, with an estimation of their uncertainty.

This note is to be submitted for approval to the project manager which has fifteen working days in which to make any comments.

8.1.5 - Test programme

The contractor will propose the test programme [one month] (4) before its scheduled date. The programme will include the operations below, in the following order:

- a diagram showing the position of the benchmarks,
- a detailed inspection by both parties, with, if necessary, a proposal for modifying the remainder of the programme in the light of comments,
- location of the loads,
- verification of the characteristics of the weighing devices (weighing, geometry),
- loading of spans (order of the different loading operations),
- the specific inspection conducted during loading: the central part of the intrados, the sides of the fixing restraint that connects the cross beam to the piers, the sides of the piers of a rigid frame bridge,
- detailed inspection after the removal of loads,
- the reference level before and after the tests,
- the characteristics of the means of access.

This note is to be submitted for approval to the project manager which has fifteen working days in which to make any comments.

Once the programme has been accepted, the contractor will provide and install stainless steel benchmarks on the edges of the deck, above the bearings and in the centre of the span. These benchmarks will be fixed into a special recess which may be drilled. The use of self-drilling plugs or powder-actuated guns is prohibited. The project manager reserves the right to install any test or monitoring device it deems justified (settlement gauge, temperature probe, strain gauge, etc.) and to conduct measurements during the tests. The contractor:

- will provide any means of access that may be required to the different parts of the structure during each phase of the tests,
- will mark the position of the loading devices,
- will provide the loading devices in accordance with the loading cases described above and perform the scheduled loading operations, directing the manoeuvres.

The results of the detailed inspections and level-taking commissioned by the construction authority must show the following:

(3) Value to be specified by the project manager
(4) Value to be specified by the project manager

- absence of abnormal cracking or other anomalies before loading operations,
- absence of detectable disorders before or after loading operations,
- absence of residual settlement.

If these requirements are not met, the contractor will, within one month, provide explanations and if necessary propose remedial operations then carry them out once they have been agreed by the project manager.

8.2 - Structure for which measurements of different types are required (5)

8.2.1 - The objectives of the tests

The objectives of these tests are as follows:

- to assure the client that the delivered structure is fully capable of carrying the test loads, and thus perform its function in terms of bearing capacity,
- to verify that the mechanical behaviour of the loaded structure conforms to its design modelling.
- to constitute one of the elements of the description of the reference state of the structure.

8.2.2 - Organization of the tests

The contractor will be responsible for the general organization, drawing up the calculation notes, designing the test programme, and interpreting the tests. In addition, the contractor will provide the project manager with the necessary access to the structure in order for the staff responsible for inspections and testing to be able to perform their tasks, and also provide the lorries or weights that are required for the tests. The costs of these services are to be borne by the contractor.

The costs of inspections and level taking are to be met by the project manager. These operations are conducted jointly with the contractor. The contractor will direct the tests, the interpretation of which will be submitted to the project manager for approval.

As a derogation from Fascicle 61 title II, the concrete may be less than 90 days old when the tests are performed. The minimum time since the last concrete was cast is one month, on condition the concrete strength values given in the calculation notes are obtained.

8.2.3 - Test loads

The structure will be subjected to general static loads which generate effects that are between those of frequent traffic loads and three-quarters of the effects of the characteristic traffic loads defined in Eurocode EN 1991-2, without, however, being less than the effects of a load of 2.5 kN/m^2 evenly distributed over the pavement(5).

It is necessary to calculate the stresses that are generated by the test loads. In practice, for decks which work mainly in flexion, more attention is paid to those parts of the structure which experience the greatest flexural stresses, which are referred to as “principal sections”. Generally, this is one section in the middle of each span and sections on intermediate bearings. Stationary test vehicles are to be placed on the carriageway. These may be moved close to each other either longitudinally or transversally, irrespective of the lane divisions on the carriageway.

To simplify conduct of the tests, and to avoid undue overloading of one section of the structure, it is necessary to limit the number of test vehicles on each test section. It may thus be accepted that the stresses generated by test loads in a few “principal sections”, in particular sections above intermediate bearings, may be 10% lower than the stresses caused by frequently occurring traffic loads.

Dynamic effects are to be monitored qualitatively by performing simplified tests under moving loads:

(5)The construction manager will specify the additional loads to be applied if the bridge is subjected to exceptionally heavy traffic (type D, E and super E exceptional loads)

• A number of vehicles equal to the number of lanes is selected from among those used for the static loading tests, giving preference to those with the heaviest axles. These vehicles will be positioned side by side facing in the same direction and move from one end of the bridge to the other at a safe speed,

• A braking test can be conducted on the structure using a heavy vehicle of more than 19 tonnes. This test can detect abnormal movements (compression of joints, irreversible deformation of bearings, etc.).

Testing of the entire footpath is not required for bridges whose main beams support both the carriageway and the footpaths. The only requirement is to test the local strength under the effect of test loads.

8.2.4 - Design hypotheses

The contractor will draw up the design hypotheses note at least [one month] (6) before the date scheduled for the delivery of the calculation note for the tests. This note is to be submitted for approval to the project manager which has fifteen working days in which to make any comments.

8.2.5 - Calculation note

Prior to the tests, the contractor will draw up the calculation note [3 months] (7) before the scheduled test date. This will include:

- the calculated probable state of the structure on the day of the tests under the effect of permanent loads,
- the calculated effects of the frequent characteristic traffic loads,
- the impact on the structure of natural factors such as temperature, thermal gradient (the temperature differences between different parts of the bridge), in order to be able to interpret in-situ measurements. The contractor will evaluate the need to record the movement of the deck in the course of a thermal cycle during the tests as well as in the days before or after them.
- the selection of test loads and their simulation using lorries set aside by the contractor. The effect of these loads will be calculated without weightings, taking account of the real characteristics of the lorries (axle loads, wheelbase, etc.).
- statement of the acceptable uncertainty with regard to the weight of the loading convoys and their position,
- statement of the successive positions of the lorries and the principal sections to be tested in each position. The kinematics of lorry movements should be planned so effects greater than the test loads are not generated in any principal section.
- quantification of the physical quantities that are representative of the mechanical operation of the bridge during the tests and tracing the pseudo influence lines if these are required. The design office will determine the limit value of this physical quantity and the tests will be halted if this is attained. In the absence of specific analysis, the figure of 1.5 times the nominal design value should be taken.
- uncertainties as regards the calculation of physical quantities and as regards the measurements should be made clear,
- determination of the settlement of bearings under traffic loads, if this is large (> 1 mm). This note will be submitted for approval to the project manager which has [30] working days (8) to make any comments.

Subsequent to the tests, within [5] working days (9) after the tests, the contractor will deliver the test report with a test interpretation document covering the following points:

- verification of the experimental and theoretical results, and explanation of any divergences from them,

(6)The construction manager will set the time limit with reference to the size of the structure, taking account of the time required to obtain an approval certificate

(7)The construction manager will set the time limit with reference to the size of the structure, taking account of the time required to obtain an approval certificate

(8)The construction manager will set a time limit with reference to the size of the structure, taking account of the time required to obtain an approval certificate

(9) The construction manager will set a time limit that is compatible with the acceptance process

- if necessary, additional investigations based on more realistic models. This relates especially to local loading tests when the measured values are unsatisfactory but nevertheless indicate that the tested members are functioning in a homogeneous manner,
- halting of the tests on members of a given type if a member appears to be deficient as the result of poor manufacturing and/or the nominal value for the representative physical quantities is exceeded,
- The contractor must analyze the cause of these defects, propose corrective measures to the project manager within a time limit that has been fixed by administrative order (10) and identify all the deficient members.

The tests on these members must be repeated, at the contractor's expense, after repairs. The post-test document will be submitted for approval to the project manager which has [10] working days to make any comments.

8.2.6 - Test programme

The contractor will propose the test programme [two months] (11) before the scheduled date for the tests. This document will be submitted for approval to the project manager which has [20] working days to make any comments. The programme will include the operations below, in the following order:

- a list of those taking part in the tests, a list of the managers and the person responsible for the overall coordination of the operations,
- a diagram showing the position of the benchmarks and the measurement devices, in accordance with the measurement programme,
- a description of the means of access required in order to install the instrumentation and perform the measurements. [the means of access that are required in order to gain access to the following points ……… are as follows…………….] (12),
- the equipment required for communication between the various participants, which must be tested on the structure one week before and the day before the tests [the minimum equipment to be made available are as follows] (13),
- the initial detailed inspection performed by both parties with, if necessary, a modification of the rest of programme subsequent to any comments,
- the positioning of the loads,
- verification of the characteristics of the loading devices and in particular the weighing certificates delivered before the tests and after the tests in the case of lorries subjected to heavy rain after they were first weighed,
- the loading of the bearings,
- the plan for moving the lorries,
- the loading of the spans in accordance with the cases specified in the calculation note,
- local loading operations,
- dynamic loading operations,
- the measurements planned during each loading operation,
- the specific inspection conducted during each loading operation: the central part of the intrados of the loaded spans, the bearings, any cracked areas or problems identified during the first detailed inspection … [to be completed as necessary] (14),
- the final examination of the structure before the removal of loads. This examination will then be supplemented by the Initial Detailed Inspection (IDI) if required by the project manager. Acceptance of the structure may be conditional on the results of this IDI.

(10) The construction manager will set a time limit by administrative order and postpone acceptance
(11) Value to be modified according to the size of the structure
(12) The construction manager will decide on which parts of the structure are to be inspected and the appropriate access facilities on the basis of the size and type of the bridge.
(13) The construction manager will decide on the communications equipment on the basis of the size and type of the bridge
(14) The construction manager will decide which parts should be accessible in accordance with the inspection techniques to be applied.

- the reference levels before and after the tests,
- a dimensioned drawing showing the levelling points [to be supplemented if necessary] (15).

The contractor will install stainless steel benchmarks on the edges of the deck, above the bearings and in the centre of each span [and on …] (16). These benchmarks will be fixed into a special recess which may be drilled. The use of self-drilling plugs or powder-actuated guns is prohibited. The project manager reserves the right to install any test or monitoring device it deems justified (settlement gauge, temperature probe, strain gauge, etc.) and to conduct measurements during the tests.

The contractor will provide any means of access that may be required to the different parts of the structure during each phase of the tests. It will mark the position of the loading devices. The contractor will provide the loading devices in accordance with the loading cases described in the calculation note and perform the scheduled loading operations.

8.2.7 - Articles that relate specifically to various structures

Torsionally rigid and transversally indeformable decks:

This involves prestressed concrete box beam, orthotropic metal slab and steel and concrete composite bridges. It is acceptable to place the markers at the edge of the extrados beyond the carriageway. The torsional rotation of the deck will be obtained from the difference between the deflections on the two edges

For each principal section, the test load is generally located midspan and distributed over the different lanes.

Some off-axis loading operations, at least one on each span, will enable the structure to be subjected to torsional stresses.

Torsionally flexible and transversally rigid decks:

These consist of two beam steel and concrete composite bridges. It is necessary to conduct both midspan and off-axis loading on each principal section, while monitoring the deflections of the two beams.

Transversally deformable decks:

This category includes composite concrete and steel bridges consisting of a small number of box beams or beams (≥ 3), wide rib decks and some postensioned prestressed girder decks. The deflections of each beam must be monitored. The tests will include loading of the span intended to validate the distribution of traffic loads between the different beams by measuring the deflections on each beam, and a loading procedure intended to test the principal sections of each beam, concentrating the heavy loads in one or two lines above the beam.

Curved and skew bridges:

The measurement points for deflections are to be positioned on both edges.

Pedestrian and cycle bridges:

Both static and dynamic tests will be performed. In the case of static tests, the load will consist of weights, or if possible vehicles, with an appropriate weight and should generate stresses that are between the effects of frequent traffic loads and 0.8 times of the effects of the characteristic traffic loads defined in Eurocode EN 1991-2. For the dynamic tests, the contractor will determine the excitation load, the metrological requirements, the number of sensors and the number of measurement modes, in such a way as to validate the theoretical modal analyses. The loading tests must include the verification of the good performance of the deck as regards bending, swaying and twisting.

Local static loads:

(15) The construction manager will supplement the requirements based on Fascicle 4 of the second part of the Technical Guidelines for the Monitoring and Maintenance of Engineering Structures

(16) The construction manager will specify, if necessary, the postions where additional benchmarks are to be installed. It will also add any other measurement device.

This involves structures with metal cross girders and brackets, suspenders, and footpaths that extend more than 1.50 m beyond the edge beam. At least 10% of these should be loaded. In the case of members that are subjected to major stresses caused by local loads and general loads acting at the same time, the local loads should be left in place while the tests involving general loading of the pavement are performed.

For cable-stayed bridges:

The calculation will involve the deflection of the deck, the longitudinal displacement of the towers and the deck, and variations in the tension of the stay cables. In the case of the main span, the measurement points are to be placed 25 metres apart or at least every quarter of the span, whichever is the smaller. In particular, the tests will include distributed loads in order to apply flexural stresses to the towers and concentrated loads in order to apply flexural stresses to the stay cables and the deck.

For suspension bridges:

The calculation will involve the deflection of the deck, the longitudinal displacement of the towers and the deck, and variations in the tension of the stay cables. In the case of the main span, the measurement points are to be placed 25 metres apart with a minimum requirement of every quarter of the span. In particular, the tests will include distributed loads in order to apply flexural stresses to the towers and concentrated loads in order to apply stresses to the suspenders and flexural stresses to the deck.

For arch bridges:

The calculation will include the stresses and deformations in the deck and arch above the small piers and between them, the rotation of the supporting structure and variations in the moments at the base of the arch during each principal phase of the tests. In particular, these phases will include the loading of each span of the deck and general load in order to apply stresses to the arch.

For bow-string bridges:

The calculation will involve the determination of the stresses and deformations of the deck and the arch at least every quarter of the span during each principal phase of the tests. These phases will include, in particular, the loading of the two half spans, of the entire span and localized loading.

For portal bridges:

In the case of portal bridges, measurements will involve the deflection of the deck, the longitudinal displacement of the deck, and the rotation at the junction between the deck and the inclined leg and at the base of the inclined leg. The measurement points for the deflection of the deck will be located at its junction with the inclined leg and at least every quarter of the span.

For flexible structures:

With regard to large span bridges (> 200 m), cable bridges and footbridges: it is impossible to draw up standard requirements for these types of structure.

8.2.8 - Test reports

Within ten working days the contractor must deliver the test reports to the project manager. These will cover the following points:

- the exact time at which all the operations were performed,
- a description of these operations and any changes to the test programme and the reasons for them,
- a list of the vehicles used and their characteristics (dimensions, axle load, etc.),
- the exact positions of these vehicles during each phase of the tests,
- the results of the measurements made in collaboration with the project manager,

- observations made during the various inspections of the structure, before, during and after the tests.

8.2.9 - Validation of the tests

The results of measurements and observations must meet the following requirements:

- no unpredicted movement should be detected during loading of the bearings,
- during loading of the spans, the measurements should be within the range between [-20 % and +10 %] of the probable calculated values,
- the validation of the measurements must take into account any thermal effects that have been identified,
- during loading of the spans, the deformations must be proportional to the stresses caused by the loading operations,
- the deformations must disappear completely after removal of the loads,
- the inspections and examinations must reveal an absence of any detectable disorder during or after the loading operations.

In the event of these requirements not being met, the contractor must provide explanations within a time limit that is laid down by administrative order according to the severity of the nonconformities. (17), and if necessary propose operations to achieve conformity and, once the agreement of the project manager has been obtained, perform them. The costs of repeating any part of the tests are to be met by the contractor.

(17) The construction manager will set a time limit by administrative order and postpone acceptance

9 - Annex 2

Data sheets on the measurement equipment and its field of use

This annex lists the measurement devices that are most frequently used during tests on road bridges and footbridges. These devices belong to five categories depending on the type of measurement made:

Devices for measuring displacement:

- mechanical flexigraphs;
- displacement sensors;
- laser flexigraphs;
- levelling equipment
- motorized theodolites

Devices for measuring deformation:

- electric gauges;
- vibrating wires;
- strain gauges;
- optical fibres;
- curvemeters.

Devices for measuring rotation:

- levels or inclinometers.

Devices for measuring vibrations:

- accelerometers;
- geophones.

Devices for weighing vehicles:

- weighbridges.

Readers should refer to section 5.2 of this document for further details concerning the type of measurements to be made according to the type of bridge and the investigated effects.

Mechanical flexigraph (Jules Richard type)

Figure 15: *Mechanical flexigraph.*

Principle:

- Apparatus connected to the deck by an INVAR wire
- Movements amplified by a mechanical system
- Records on a graduated drum

Field of use

- Deflection measurements on standard and non-standard bridges with heights of less than 30 metres.
- Precautions are necessary above 10 m, depending on the size of the deflections and the presence of wind.

Advantages:	***Disadvantages:***
Independent device requiring no power supply	- Installation of the invar wire - Operator required to start drum, identify loading cases and load the paper.

Metrological features:

- Measurement range: 0.1 mm to 10 cm
- Resolution: 0.1 mm
- Measurement uncertainty: 0.1 to 0.5 mm according to installation and amplification.

Displacement sensors

Figure 16: *Displacement sensor.*

Principle:

- Displacement sensor connected to the deck by an invar wire or fixed to the end of a telescopic pole.
- Transformation of displacement into tension
- Data recorded by a data acquisition unit and/or a graphic recorder

Field of use

- Deflection measurements on standard and non-standard bridges with heights of less than 30 metres.
- The use of a pole to support the sensor is restricted to bridges with headroom of less than 6 m.
- Precautions are necessary above 10 m, depending on the size of the deflections and the presence of wind.

Advantages:	***Disadvantages:***
Measurements are centralized, which saves time during bridge loading operations. Fairly rapidly installed if poles are used. (No need for bonding or clamping to the intrados.)	- Installation of the invar wire - Need for an electrical connection between the sensors and the measurement unit. - Height limit when used with a pole.

Metrological features:

- Measurement range: 0.01 mm to several centimetres
- Resolution: 0.01 mm
- Measurement uncertainty: 0.1 t 0.5 mm according to installation.

Laser Flexigraph

Figure 17: *Laser Flexigraph*

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Principle:

Measurement of the deflection of a point on the structure with respect to a reference laser beam.

Field of use

High bridges over rivers or railway tracks.

Advantages:	***Disadvantages:***
Continuous recording of deflections on high bridges over rivers or railway tracks. Sufficiently accurate for flexible structures, and for rigid structures if the sight distance is optimized.	- Beam is sensitive to the thermal and luminous environment. - Older versions of the equipment difficult to use (slow to set up). - Difficult adjustments. - Accuracy over long distances insufficient for rigid structures, in particular in the case of day-time use in the open air. - Need to monitor the rotation of the transmitters positioned on and/ inside structures. - Users must be qualified.

Metrological features:

- Measurement range: 0.5 mm to 30 cm
- Resolution: 0.2 mm
- Measurement uncertainty: 0.2 mm to 1 mm depending on the site conditions.

High-precision level + INVAR rods

Figure 18: *High-precision level.*

Principle:

Indirect measurement of deflection by elevation difference read on an invar rod before, during and after loading. Readings may be taken by radiation or traversing depending on the size of the structure and how the vehicles are arranged.

Field of use

Standard bridges of limited size. Measurement principle particularly suitable when access to the underside of the structure is difficult or impossible (bridges over rivers, railway tracks or very highly trafficked roads).

Advantages:	***Disadvantages:***
Measurement principle extremely simple and quick to set up, if the number of measurement points is small, on condition there is only one station and the sight distances are kept as small as possible.	Recording of measurements is not continuous. Measurement principle very complex when there is a large number of widely-spaced levelling points. It is necessary to limit sight distances to 30 m and stabilize the rods. Not possible to measure deflections under moving loads. Need for benchmarks to be fixed to the structure and for external reference points[2].

Metrological features:

- Measurement range: 0.1 mm to several tens of cm
- Resolution: 0.1 mm
- Measurement uncertainty: 0.2 and 0.5 mm depending on the wind, temperature and relative humidity.

Motorized theodolite

Figure 19: *Motorized theodolite.*

Principle:

Determination of the coordinates of targets from a measurement station. Deflection measurement obtained from the difference in elevation.

Field of use

Very high bridges over rivers or railway tracks (can be used inside box girders).

Advantages:	***Disadvantages:***
Measurements can be recorded.	- Need for preliminary examination of the site by qualified staff. - Need to set up targets. - Sensitive to refraction. - Precautions required in rainy weather. - When used inside box girders rotations must be considered, for distance correction and other purposes.

Metrological features:

- Measurement range: not applicable
- Resolution: up to 0.1 mm depending on instruments
- Measurement uncertainty, sight distances less than 100 m in good visibility: 0.2 to 0.5 mm
  sight distances greater than 100 m or in poor visibility: > 1 mm

Electrical gauge

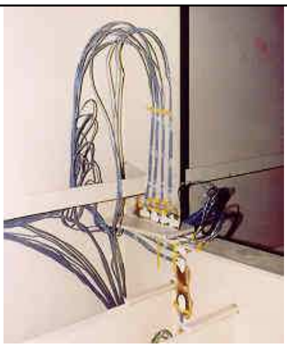

Figure 20: *Electrical gauge.*

Principle:

This consists of a high-resistance wire which is bonded to the structure. Deformation of the structure changes its length and therefore its electrical resistance which is measured by a Wheatstone bridge.

Field of use

- Measurement of deformation in concrete and steel.
- The monitoring locations must be made accessible for instrumentation purposes.

Advantages:	***Disadvantages:***
- Proven sensitivity and reliability - If well installed can be used subsequently, perhaps for bridge monitoring	- Access required to the monitoring locations and installation must be extremely careful. - Measurements on cracked concrete may not be meaningful.

Metrological features:

- Measurement range: $\pm$ 2.10^{-3} (relative deformation)
- Resolution: 10^{-6} (relative deformation)
- Measurement uncertainty: 1 to 10.10^{-6} (relative deformation)

Vibrating wire

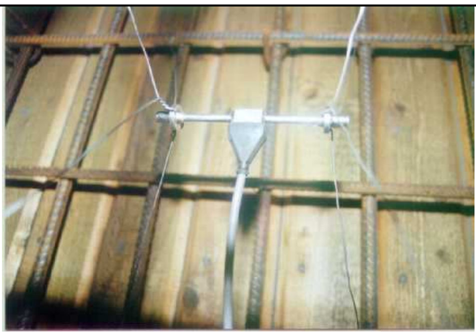

Figure 21: *Vibrating wire*

Principle:

- A wire of known length, stretched with a given force has a known resonance frequency.
- If the length of the wire varies, so does its resonance frequency.
- By measuring the above it is possible to find the lengthening of the wire.

Field of use

- Measurement of deformation in concrete
- Several technological variants exist. Some must be embedded in the concrete; others can also be fixed to facings.

Advantages:	***Disadvantages:***
- Proven sensitivity and reliability - Little temporal drift	- Measurement locations must be identified before the bridge is built so the sensors can be embedded in the concrete.

Metrological features:

- Measurement range: $\pm$ 1.10^{-3} (relative maximum deformation)
- Resolution: 0.2.10^{-6} to 5.10^{-6} (relative deformation)
- Measurement uncertainty: 3 to 15.10^{-6} (relative deformation)

Strain gauge

Figure 22: *Mechanical strain gauge.*

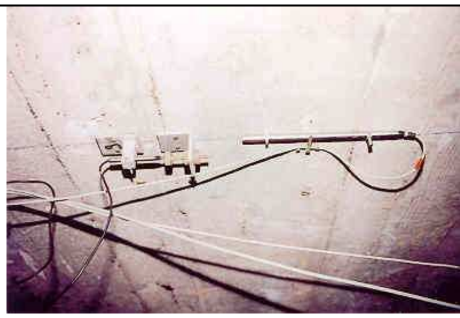

Figure 23: *Inductive strain gauge.*

Principle:

A sensor with a resolution of one micrometre or less is inserted in a mechanical assembly. This assembly is placed on measurement bases consisting of pairs of studs fixed at predefined spacings onto the structures to be monitored.

Field of use

- Measurement of deformation in concrete and steel.
- The monitoring locations must be instrumented in advance.
- This method is suitable for measuring deformation due to long duration loads.

Advantages:

- Proven sensitivity and reliability
- Permits monitoring (the original purpose of the device).

Disadvantages:

- As many strain gauges as measurement points are required in order to measure the deformations caused by short duration loads.

Metrological features:

- Measurement range: 1 to 5.10^{-3} (relative deformation)
- Resolution: 1.10^{-6} (electrical sensors)
  1.10^{-6} (mechanical sensors)
- Measurement uncertainty: 1.10^{-6} (electrical sensors)
  10.10^{-6} (mechanical sensors)

Optical fibres

Figure 24: *Optical fibre.*

Principle:

The optical fibre is fixed to the structure. Deformation of the structure changes its length and hence the optical signal transmitted by the fibre.

Field of use

- Measurement of deformation in concrete and steel.
- The monitoring locations must be made accessible for instrumentation purposes.

Advantages:

- Not affected by moisture and the electromagnetic environment

Disadvantages:

- Fragile
- Access required to the monitoring locations and installation must be extremely careful.
- Need for relatively costly specific equipment
- Need for calibration

Metrological features:

This technique has not been used sufficiently for it to be possible to state generally applicable values. Tests and calibration are required before each application.

Curvemeters

Figure 25: *Curvemeter.*

Principle:

A rigid beam is brought into contact at three points (2 fixed, one mobile) with a structure. Any curvature of the structure affects the mobile point, whose displacement is measured.

Field of use

Measurement of the curvature of a deck subjected to an excessive load.

Advantages:	***Disadvantages:***
- Simple to use - Real time use possible	Precautions necessary during use

Metrological features:

- Measurement range: greater than possible curvature
- Resolution: 1.10^{-7} m^{-1}
- Measurement uncertainty: 1 to 10.10^{-6} m^{-1}

Level – Inclinometer

Figure 26: *Level – inclinometer.*

Principle:

- Manual devices: horizontal calibration of a bubble with a micrometer screw
- Electrical devices: pendulum system

Field of use

- Measurement of rotation at the location of the device.

Advantages:

- Proven sensitivity and reliability
- Manual devices: it is possible to use the device at a succession of measurement bases.
- Electric devices: the output can be recorded and read at a distance.

Disadvantages:

- Difficult adjustments

Metrological features:

	levels	manual inclinometers	electrical inclinometers
- Measurement range:	0.1 rd	10^{-2} rd	$\pm$ 6.10^{-2} rd
- Resolution:	2.10^{-4} rd	$1,5.10^{-6}$ rd	10^{-6} rd
- Measurement uncertainty:	5.10^{-4} rd	2.10^{-6} rd	2.10^{-6} rd

Accelerometers

Principle:

- The sensor is placed on or fixed to the part of the structure to be monitored.
- It is connected to a charge amplifier which conditions the signal.
- The device outputs a voltage that is proportional to the acceleration which is recorded.
- The recordings are then subjected to spectral analysis which identifies the frequencies and damping.

Field of use

- Any part of a structure that is subjected to vibration.

Advantages:	***Disadvantages:***
- Measurement straightforward	Requires: - a measurement chain - a data analysis chain - qualified staff

Metrological features:

- Measurement range: 0.1 to 10 kHz
- Resolution: 0.1 Hz

Geophones

Principle:

- The geophone is an electrodynamic velocity sensor that is placed on or fixed to the part of the structure to be monitored.
- It outputs a voltage that is proportional to the acceleration which is recorded.
- Processing the recorded data makes it possible to obtain the speeds of displacement, dynamic displacements and the natural frequencies of the part of the structure.

Field of use

- Any part of a structure that is subjected to vibration

Advantages:	***Disadvantages:***
- Measurement straightforward	Requires: - a measurement chain - a data analysis chain - qualified staff

Metrological features:

- Measurement range: 0.8 to 300 Hz
- Resolution: 0.1 Hz

Weighbridge

Figure 27: *Weighbridge*

Principle:

A weighbridge consists of a rigid metal plate that is placed on a base equipped with force sensors. Its purpose is to measure the total weight of vehicles that are placed on it. It is calibrated using legal metrological procedures for commercial transactions. It can be used for measuring the forces exerted by parts of vehicles, on condition the entire vehicle is horizontal and at the same level.

Axle scales and moveable wheel scales also exist and can be used when installed in a special pit.

Field of use

Weighing lorries, isolated axles or axle groups.

Precautions:

- Possession of a metrological notebook, the periodic metrological verification certificate dating from less than one year, and the relevant inspection sticker.
- All weighbridges must belong to class III as defined by the OIML (International Organization of Legal Metrology).
- Axle scales or wheel scales must belong to OIML class III or IV.
- Access and egress to the weighbridge must be in precisely the same plane as its deck.
- The axle scale or the wheel scale must be in precisely the same plane as the platform.

Metrological features:

- Measurement range:
  * weighbridge 10 to 600 kN (depending on the equipment)
  * axle weighing 10 to 200 kN
  * wheel weighing 5 to 100 kN.
- Resolution: class III: 0.5 %
  class IV: between 2 and 4%
- Measurement uncertainty for a weighbridge for:
  * whole vehicle: 1% of the load
  * weighing of an isolated axle or an axle group: 3 % of the load
- Measurement uncertainty for a moveable weighbridge: 2 to 5 % of the load.

AVAILABLE TECHNIQUES FOR MEASURING DEFLECTIONS

FRAMES – RIGID FRAME BRIDGES

(Permissible uncertainty: 0.1 to 0.2 mm depending on the theoretical deflection value)

	POSSIBLE TECHNIQUES							
	Access constraints	Location of measurement points	Jules Richard fleximeters	Inductive displacement sensors	Laser flexigraphs	High-precision level and invar rod	Motorized theodolites
Height of span less than 6 m	Access under bridge possible	intrados	yes	yes	(3)	(3)	(3)
	Access under bridge impossible	extrados	(3)	(3)	(3)	yes	yes
Height of span more than 6 m	Access under bridge possible	intrados	yes (1)	yes (1)	(3)	yes (2)	yes (2)
	Access under bridge impossible	extrados	(3)	(3)	(3)	yes	yes

(1) Cradle required to fix the invar wire.
(2) Precision sometimes inadequate.
(3) Inadvisable or impossible.

AVAILABLE TECHNIQUES FOR MEASURING DEFLECTIONS

Reinforced or Prestressed Concrete Slabs; Ribbed slabs; Reinforced or Prestressed Concrete Beams; embedded girders

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(Permissible uncertainty: 0.1 to 0.2 mm depending on the theoretical deflection value)

	POSSIBLE TECHNIQUES							
	Access constraints	Location of measurement points	Jules Richard fleximeters	Inductive displacement sensors	Laser flexigraphs	High-precision level and invar rod	Motorized theodolites
Height of span less than 6 m	Access under bridge possible	intrados	yes	yes	(4)	(4)	(4)
	Access under bridge impossible	extrados	(4)	(4)	yes (2)	(4)	yes (3)
Height of span more than 6 m	Access under bridge possible	intrados	yes (1)	yes (1)	yes (2) (3)	(4)	(4)
	Access under bridge impossible	extrados	(4)	(4)	yes (2)	(4)	yes (3)

(1) Cradle (or gangway) required to fix the invar wire.
(2) Possible if the sight distance is less than 50 m and the theoretical deflection greater than 5 mm
(3) Precision sometimes inadequate.
(4) Inadvisable or impossible.

AVAILABLE TECHNIQUES FOR MEASURING DEFLECTIONS

Composite or metal bridges (apart from box girder or arch bridges)

(Permissible uncertainty: 1% of the theoretical deflection)

	POSSIBLE TECHNIQUES							
	Access constraints	Location of measurement points	Jules Richard fleximeters	Inductive displacement sensors	Laser flexigraphs	High-precision level and invar rod	Motorized theodolites
Height of span less than 6 m	Access under bridge possible	beam ends	yes	yes	(4)	(4)	(4)
	Access under bridge impossible	beam ends	(4)	(4)	yes (2)	(4)	yes (3)
Height of span between 6 et 30 m	Access under bridge possible	beam ends	yes (1)	yes (1)	yes (2) (3)	(4)	yes (3)
	Access under bridge impossible	beam ends	(4)	(4)	yes (2)	(4)	yes (3)
Height of span more than 30 m		beam ends	(4)	(4)	yes (2)	(4)	yes (3)

(1) Cradle (or gangway) required to fix the invar wire.
(2) Possible if the sight distance is less than 50 m and the theoretical deflection greater than 5 mm, however, the uncertainty will be between 3 and 5%; need to measure rotations if transmitters are installed on bearings.
(3) Precision sometimes inadequate.
(4) Inadvisable or impossible.

AVAILABLE TECHNIQUES FOR MEASURING DEFLECTIONS

Box beam bridges

(Permissible uncertainty: 2 % of the theoretical deflection)

		POSSIBLE TECHNIQUES						
	Access constraints	Location of measurement points	Jules Richard fleximeters	Inductive displacement sensors	Laser flexigraphs	High-precision level and invar rod	Motorized theodolites
Height of span less than 6 m	Access under bridge possible	lower slab	yes	yes	(4)	(4)	(4)
	Access under bridge impossible	lower slab	(4)	(4)	yes (2)	(4)	yes (3)
Height of span between 6 et 30 m	Access under bridge possible	lower slab	yes (1)	yes (1)	yes (2) (3)	(4)	yes (3)
	Access under bridge impossible	lower slab	(4)	(4)	yes (2)	(4)	yes (3)
Height of span more than 30 m		lower slab	(4)	(4)	yes (2)	(4)	yes (3)

(1) Cradle (or gangway) required to fix the invar wire.
(2) Possible if the sight distance is less than 50 m and the theoretical deflection greater than 5 mm, however, the uncertainty will be between 3 and 5%; need to measure rotations if transmitters are installed on bearings or inside box girders.
(3) When transmitters are installed on bearings or in box beams.
(4) Precision sometimes inadequate.
(5) Inadvisable or impossible.

AVAILABLE TECHNIQUES FOR MEASURING DEFLECTIONS

Suspension or cable-stayed bridges, arches

(Permissible uncertainty: 2 % of the theoretical deflection)

		POSSIBLE TECHNIQUES				
	Location of measurement points	Jules Richard fleximeters	Inductive displacement sensors	Laser flexigraphs	High-precision level and invar rod	Motorized theodolites
Suspension bridges Cable-stayed bridges	To be specified in the CCTP	(2)	(2)	yes (1)	(2)	yes
Arch bridges						

(1) – Sight distances must be reduced as far as possible
- Need to measure the rotations of the transmitters
- Installation of the devices should take account of horizontal deformation which may make the laser flexigraph unusable

(2) - Inadvisable or impossible

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This guide is intended to the building owners, the project superintendents, the engineers of the engineering and design departments and of the laboratories, which have to order, design, organize, carry out, and interpret the tests under load of the road and pedestrian bridges.

It describes the whole of the operations of preparation, realization and checking of the load tests, which make it possible to ascertain the good behaviour of the structures before their reception.

While awaiting the regulations of Eurocode >EN 1991-2, the tests of the road bridges are presently performed according to the Booklet 61 Title II of the common Specifications.

This guide is also meant to prepare the transition towards Eurocode, and to constitute the base of a normative document that will go with it.

In the mean time, the regulations of this guide must be included in the contracts binding the operators to the building owner. For this purpose, it includes standard clauses, which will have to be inserted in the administrative and technical parts of the engineering and construction contracts.

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