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Contents

Tables

Appendices

1 General Requirements

1.1 Purpose, Scope and Description of the Monitoring Works

Package 6 of the Kings Cross Station Redevelopment Project comprises modification of the existing Grade I listed West Side Buildings and the Suburban Train Shed.

A comprehensive monitoring programme is required for structures that are potentially affected by the works, in order to indicate whether movements and stresses are developing as expected or whether elements are becoming unstable as the works progress. As works will be undertaken while the station remains operational so a collapse will have severe consequences for construction workers and for the public.

This specification requires

- The installation and commissioning of monitoring systems described, and others as instructed by the Employer's Representative
- The ongoing collection, processing, storage, reporting and dissemination of the data obtained, and
- The development and implementation of response plans, as defined below, when monitoring indicates that trigger levels have been reached.

The monitoring systems required include:

- 3D monitoring of façade movements of specific portions of the West Range Building, Main Trainshed, and Suburban Trainshed Walls using networks of automated theodolites.
- Settlement monitoring of elements of the West Range Building by precise levelling
- Movement measurement at existing defects (cracks) in the various façades
- Strain gauge monitoring of the temporary works ties at gridlines W3 to W7 and W19 across the Main Trainshed in such a way that these can be used to determine the force in the ties.

A comprehensive monitoring system is in place on the site and being operated by Soldata to monitor effects of the London Underground station redevelopment, which will affect the West Range Buildings and other elements of Network Rail infrastructure. As this system is to remain in operation until 6 months after construction works on the Underground project are complete there is likely to be an overlap period with the two monitoring systems.

1.2 Objectives of the monitoring programme

The objectives of the monitoring programme are:

- To determine the ambient behaviour of existing structures prior to significant construction works commencing
- To assess the effects of construction work on the existing structures, which may or may not form part of the Project.
- To maintain detailed weather records in order to assess the effects of environmental conditions upon the monitoring data obtained.
- To give timely warning that structures are not behaving as predicted and that a risk of significant damage or collapse is developing, allowing contingency measures to be adopted.

1.3 Definitions

Where referred to in this specification the following terms are defined:

Employer's Representative (ER)

Such person(s) as may be nominated by the Employer to act as such for the purposes of the Contract. Refer to the Network Rail 12 Contract for the Works.

Trigger levels

General term for *Warning* and *Action Levels,* which refer to particular values of displacement, stress or strain at which pre-defined actions are initiated. Values above the Warning Level and below the Action Level are in the 'amber' zone, using green, amber and red traffic light system for describing the monitoring readings. Values above Action Level lie in the 'Red' zone. Values below warning level lie in the 'green' zone.

Warning Levels

Warning Levels correspond to the movements above which "Slight Damage" (BRE Damage Category 2) may occur to buildings and utilities in the cumulative long-term condition, or where permissible movements agreed with the owner may be exceeded.

Alternatively, Warning Levels may be set at intermediate stages of the works to control short-term movements at that stage, to ensure that the long term response does not exceed acceptable levels.

Cumulative Warning Levels have been set for railway track in tunnels at the "Maintenance Limit" (LUL standards), or the relevant Network Rail track standards, where such track tolerances are available[1].

Action Levels

Action Levels correspond to movements above which "Moderate damage" (BRE Category 3) may occur to buildings and utilities in the cumulative long-term condition, or where permissible movements agreed with the owner may be exceeded.

Alternatively, Action Levels may be set at intermediate stages of the works to control short-term movements at that stage, to ensure that the long term response does not exceed acceptable levels.

Contingency plan

A plan of action initiated by the Contractors in consultation with the Employer's Representative when trends in the data indicate that a Warning Level may be reached in the near future or when a sudden breach of the Warning Level occurs. The plan is likely to include increased frequency of monitoring, detailed assessment of ground movements and structure response and re-assessment of the temporary works design.

Action plan

A plan of action initiated by the Contractor and the Employer's Representative when trends in the data indicate that an *Action Level* may be reached in the near future or when a sudden breach of the *Action Level* occurs. The plan is likely to include temporary cessation of work, installation of additional temporary support measures, increased frequency of monitoring and redesign of the temporary and permanent works.

Commissioning readings

The process of obtaining initial readings from an instrument or array of instruments at the time of installation in order to demonstrate that the instrument(s) is (are) capable of obtaining the intended data and functioning as specified.

Baseline readings

The process of obtaining readings at regular intervals over a specified period of time (minimum 8 weeks in this contract) in order to identify the likely range of ambient

[1] Refer to LUL Engineering Standard E8404 and Network Rail Line Standard RT/CE/S/104.

movements, when unaffected by construction works. Subsequent construction induced movements may then be identified by comparison of monitoring data against the baseline values.

Continuous monitoring

Monitoring on a continuous basis at predetermined frequencies using an automated instrumentation and monitoring system.

Accuracy

A measure of the “correctness” of the data. That is, how close the value is to the “true” value. This can normally only be determined in a controlled laboratory environment where environmental effects (temperature, pollution haze, and vibration for example) are minimised.

Resolution

The smallest unit that can be read on the instrument.

Repeatability or Precision

A measure of the scatter or spread of data around a mean value obtained from an instrument. Includes any imprecision in the instrument itself, plus operator and environmental influences.

Calibration

The process of applying known loads or displacements to an instrument and measuring the response under controlled environmental conditions. This is carried out in the factory (to obtain gauge factors) and for some instruments again on site prior to installation. This may also be carried out whilst in service.

Damage category

A method of assigning a level of damage to a building from tunnelling induced settlement assuming that the building conforms to “Greenfield” movements. For masonry structures the damage category is usually based upon calculated tensile strains in an “equivalent beam”, deflection ratios and visible damage criteria. For other structures the category of damage may be based on limiting ground slopes, curvature and induced tensile strains.

"BRE Damage Categories" refer to levels of damage associated with degrees of movement defined in BRE Digest 251 (1995)

Instrumentation

Includes all recording devices, cabling, data-logging facilities, modems, computers and portable “down-loading” devices used to record geotechnical or structural changes induced by the proposed works.

Monitoring

The process of gathering, reducing, interpreting and reporting of data obtained from the installed instrumentation system.

Real-time monitoring

Where critical construction activities are being carried out in particular areas monitoring shall be undertaken in “real-time”. That is data will be processed and updated immediately it is obtained and shall be available for immediate viewing and interpretation by a monitoring engineer. Such monitoring is shall be used in conjunction with an automated alarm system which notifies the relevant personnel when trigger levels have been breached.

Works Package Plans

Network Rail requires works package details, Works Package Plans and construction sequences to be submitted as Works Package Plans

1.4 Contractors' Responsibilities

The following work is required for this contract:

a) The Contractor shall be responsible for the supply, calibration, quality assurance, installation, commissioning, maintenance and removal of the instrumentation as indicated on drawing series ENG-DWG-OAP-KX6-CGS-0001..

b) In conjunction with the Employer's Representative the Contractor shall be responsible for seeking and obtaining all necessary permissions to install and monitor the instrumentation throughout the life of the project.

c) The Contractor shall produce Works Package Plans in accordance with **clause 2.4**. He shall also install new instrumentation under the instruction of the Employer's Representative as required.

d) The Contractor shall design, install, maintain and make good upon removal any other instruments he considers necessary to achieve the specified field accuracy. He shall carry out investigative works as necessary in order to design his installations to the satisfaction of the Employer's Representative. He shall ensure that he is familiar with existing relevant Works Package Plans and the implications for his installation works.

e) The Contractor shall be responsible for compiling Works Package Plans for the new installation works. The Works Package Plans shall conform to Network Rail Satandards.

f) The Contractor shall install his own proprietary software operating system to operate the installed automated theodolite networks. The Contractor shall provide his calculations of the field accuracy achievable from the networks.

g) The Contractor will be responsible for the interpretation of the data insofar as he shall demonstrate a clear understanding of the impact of environmental effects and effects of immediate and long-term construction works upon the data obtained and shall identify any trends.

h) The Contractor must ensure that the monitoring results are understood in the context of the site operations and programme.

i) The Contractor shall ensure that all information regarding actual movements, rates of change and trends are communicated to operatives responsible for actual construction works and the Employer's Representative, in a timely and efficient way. This is to ensure that contingency plans can be implemented if Warning Levels are approached/exceeded and movements do not exceed Action Levels under any circumstances.

j) Instrumentation which is damaged or malfunctions during the life of the project shall be repaired or replaced.

k) Condition surveys of monitored structures will be carried out by others. The Contractor shall undertake defect monitoring in conjunction with inspection surveys (as described in **clause 2.6**).

l) Precise levelling will also be required on an intermittent basis using interchangeable eye-bolts in BRE type levelling sockets. Mortar course/cornice level surveys (**clause 2.6**) will also be required for the internal walls of the Kings Cross train shed, the south façade of Kings Cross station. The measurements will be carried out to confirm design assumptions and as an adjunct to defect monitoring and inspections surveys.

m) De-commissioning works shall include removal and making good for the entire instrumentation system. The Contractor shall ensure that re-instatement is carried out to a standard that is equivalent to or better than the condition

indicated in the condition survey reports. The standard of re-instatement shall be agreed with the Employer's Representative in the Works Package Plans.

1.5 Instrumentation Personnel

Notwithstanding any other provisions in the Contract in respect of the Contractor's staff, the Contractor's Instrumentation and Monitoring personnel shall be trained and qualified to a level commensurate with the duties on which they are engaged. The qualifications and training shall be consistent with the Contractor's own health and safety standards and with those of the owners.

The Contractor shall identify a Monitoring Engineer to be responsible for the co-ordination and implementation of the monitoring programme and the interpretation of the monitoring results.

The Contractor shall submit CV's and notice of the availability of all Instrumentation and Monitoring personnel in his Works Package Plans, including that of the Monitoring Engineer, for approval by the Employer's Representative at least five weeks before installation starts on site. Copies of all CV's shall be available for inspection on site at all times. CV's shall be updated at each change of personnel.

Readings shall, wherever possible, be taken by the same personnel. Should there be a need to change personnel, two sets of independent duplicate readings shall be taken on the same instrument at the same time by the out-going person and his/her replacement to ensure consistency in approach and quality of readings. The Contractor shall not change key instrumentation personnel without the Employer's Representative's approval and shall give at least five weeks notice of any such change.

1.6 Standards

The Works shall be executed to the satisfaction of the Employer's Representative and in accordance with this Specification and to the latest editions of Network Rail and British Standards where they are applicable. Relevant Network Rail Standards include:

NR/SP/CIV/003	Technical Approval of Design, Construction and Maintenance of Civil Engineering Infrastructure
NR/SP/CIV/088	Examination of Buildings and Station Structures

1.7 Programme of Work

The programme for monitoring works must be integrated into the programme for civil/structural works.

The Contractor shall programme his installation in order that a minimum of 8 weeks baseline readings period are obtained for all structures. Latest start dates for baseline monitoring are shown in the programme. Works Package Plans shall be submitted according to the sequence and areas in which the Instrumentation and Monitoring is to be installed.

Monitoring shall continue on all structures during the main intervention works in the West Range Building and the Suburban Trainshed and for an additional 3 months (or as otherwise directed by the Employer's Representative) after their completion to ascertain the long-term structural response

The Contractor shall make suitable allowance in his overall programme of work for the delivery, installation, testing, calibration, commissioning, reading, and maintenance of the instrumentation, as well as interpretation and confirmation of the field readings and reporting of the data in the specified format.

1.8 Permissions

The Contractor shall liaise with the Employer's Representative to obtain all necessary permits for instrument installations in the following areas as required:

a) Argent and/or London & Continental Stations & Properties (LCSP) for access to the eastern part of the St Pancras train shed and the Great Northern Hotel

b) English Heritage regarding Grade I and II listed buildings (Kings Cross Station and Great Northern Hotel

c) Local authorities (London Boroughs of Camden and Islington) for permissions to install instrumentation on public highways and paths

d) The Northern Ticket Hall main works contractor for site access as to the Northern Ticket Hall or the "Bomb Gap" in the West Range Buildings necessary

1.9 Access and Attendance

Access to surface structures shall be by prior arrangement with the owner of that structure, in conjunction with the Employer's Representative.

The Contractor shall take every practical measure to prevent damage to existing equipment and cable during the works. The Contractor shall consult with the Employer's Representative where disturbance is thought possible in order to agree acceptable alternative arrangements. Alternative proposals shall be submitted in writing to the Employer's Representative two weeks before the intended installation date.

2 Operational Requirements

2.1 Provision of Devices

Equipment and installation accessories required for the operation of the instrumentation system and recording of measurements shall be supplied by the Contractor where specified, and shall be available on Site immediately as required during installation. The Contractor shall ensure that he maintains an adequate stock of material so that the installation programme is not delayed due to delay in supply of instruments and materials. Any materials held in storage shall be securely stored where they will not suffer physical damage or damage arising from excessive moisture, extremes of temperature or other adverse environmental conditions.

All measuring devices shall be as specified and shall be manufactured by companies with proven experience in the field of tunnel and/or geotechnical instrumentation. All materials, designs and construction shall be of the highest quality to provide robust, corrosion- and vibration-resistant instruments. The accuracy and dependability of the equipment shall not be significantly affected by changes in temperature, humidity, stray currents or other adverse environmental conditions that may be encountered. Instruments shall be procured such that automatic corrections for temperature shall be applied where appropriate.

Serial numbers of reading instruments shall be recorded and noted on the measurement records.

The Contractor shall be responsible for keeping records of all calibration certificates and for sending equipment off site for re-calibration by reputable testing laboratories when required. All calibration certificates shall be retained on site and made available for viewing by the Employer's Representative or his representative upon request.

Factory calibration certificates, where appropriate, shall be provided by a reputable testing company accredited by UKAS (United Kingdom Accreditation Service). A list of laboratories accredited by UKAS may be obtained from:

UK Accreditation Service
21 – 47 High Street
Feltham
Middlesex
TW13 4UN

Tel: 0208 917 8400
website: www.ukas.com

The instrument manufacturer shall provide drawings and data describing the principal features, mode of operation, the measuring range and the degrees of accuracy of the equipment. The manufacture of all items shall be in accordance with the drawings and with the Specification and shall comply with the relevant British Standards.

All non-recoverable instrumentation used shall be new at the time of installation.

Unless otherwise specified stainless steel shall be Grade 1.4436 to EN 10088 (formerly grade 316).

The Employer's Representative may instruct that additional instruments be installed in the event of unforeseen circumstances being encountered.

The Contractor may offer alternative types of instrumentation to those specified provided they are of equal or better performance. The alternatives will be subject to the approval of the Employer's Representative. The Contractor shall provide full details of alternative systems to the Employer's Representative for approval at least 5 weeks before installation.

2.2 Location of Instruments

The locations and type of instruments are as shown on drawing series ENG-DWG-OAP-KX6-CGS-0001 , or as otherwise specified. The final location of each monitoring point as installed shall be agreed on site with the Employer's Representative and shown on as-built record drawings to be prepared by the Contractor in accordance with **clause 2.7.2.**

Monitoring systems shall be installed unobtrusively on all existing structures with minimum disruption to the owners and occupiers, at least 10 weeks in advance of significant structural works being undertaken in or adjacent to that structure.

2.3 Installation and Maintenance of Instruments

Electricity, water, ancillary equipment and cabling shall be supplied by the Contractor in consultation with the Employer's Representative. Under no circumstances shall the Contractor use hoses located on station platforms for his water supply.

The Contractor shall be responsible for making good any damage incurred during installation based upon agreed pre-construction condition survey reports to be obtained from the Employer's Representative. The Contractor shall carry out his installation and de-commissioning works in accordance with the methods and materials agreed with the relevant 3rd parties and Employer's Representative in advance of the works.

The Contractor shall install equipment according to the manufacturers' recommendations. Testing shall be undertaken as necessary to ensure satisfactory functioning of the equipment at each stage of the installation. In particular, adequate precautions shall be taken to protect the instruments from harmful effects of groundwater. Instruments found to be malfunctioning at any time shall be replaced, where possible, at the earliest opportunity.

All instruments shall be securely fixed. Fixings shall be tested for rigidity immediately after installation or when adhesives have cured as appropriate. Any fixings subsequently found to be suspect shall be re-installed/replaced as necessary at the Contractor's cost.

Instrument terminations, including any attendant wiring and terminal panels, shall be adequately protected against mechanical damage and ingress of water and dirt. The equipment shall be fixed such that it is capable of resisting air movement and pressure changes underground, or vandalism and adverse climatic conditions at surface locations. As far as practicable instruments and terminal boxes built into concrete shall be kept clear of reinforcement.

The Contractor shall take every practicable measure to prevent damage to the instruments and ancillary equipment during handling, installation and subsequent operation. Should it become apparent that a monitoring point/instrument has been damaged or lost during the course of the contract, the Contractor shall advise the Employer's Representative forthwith and the Employer's Representative may instruct the installation of a replacement point.

Wherever possible readings for individual instruments or arrays shall be taken using the same instrument. Where an instrument is to be changed (i.e. a theodolite, tape extensometer or BRE type levelling bolt for example) one parallel set of readings shall be taken with the replacement instrument to ensure continuity of reading.

The Contractor shall maintain all the instruments required for long term monitoring in a satisfactory working order for the duration of the project.

The Contractor shall ensure that all the instrumentation remains correctly calibrated. He shall carry out regular checks to confirm the validity of calibration of equipment in accordance with the manufacturer's instructions and carry out any adjustments that are found necessary.

Automated electronic data capture and remote reading facilities shall be provided where specified to minimise disruption and disturbance to occupiers and owners and provide real-time monitoring when required.

2.4 Works Package Plans

The Contractor shall provide to the Employer's Representative detailed Works Package Plans describing the installation of the Instrumentation and Monitoring system specifically addressing the requirements of the relevant third parties listed in **clause 1.8**. Works Package Plans shall be submitted not less than 5 weeks prior to the programmed start of baseline readings.

Works Package Plans shall follow the general format and content as agreed with the Employer's Representative for the existing installations.

A number of structures affected by the works are Grade I and II listed and therefore will be subject to English Heritage requirements. Separate additional method statements will therefore be required for English Heritage approval for any installation works on these structures.

The following information shall be included for the Employer's Representative's approval:

a) CV's and notice of the availability of all Instrumentation and Monitoring personnel, including that of the Monitoring Engineer, for approval by the Employer's Representative at least five weeks before installation starts on site. Copies of all CV's shall be available for inspection on site at all times. CV's shall be updated at each change of personnel.

b) Details of materials and equipment to be installed (as specified or proposed alternatives) including: Manufacturers drawings showing dimensions, manufacturers specification, principal features, mode of operation, measuring range and accuracy, type, serial number, principle of measurement, installation details, environmental limitations, power requirements, logging system, data format

c) Method of fixing and replacement procedures

d) Methods for de-commissioning and re-instatement and materials and equipment required

e) Cable type, fixings, dimensions, environmental limitations, routes and installation details

f) Proposed power and water supply arrangements

g) Data logger/Read-out boxes and radio antennae location, type, fixings

h) Longevity of materials used, grout/resin types and setting times

i) A programme for the installation testing, calibration, commissioning readings and maintenance of the monitoring systems

j) Data management system including hardware, details of the software, file structure, security systems, maintenance support, input systems, graphics capability, report types, audit procedures, data format and computer virus protection system (type, scope, update procedure)

k) Examples of previous application and efficacy of the software/data management system

l) Sample data presentation sheets for each of the different types of instrumentation to be installed

m) Method of review and interpretation of the data to ensure that trigger or Action Levels are not exceeded

n) Approvals, permits and permissions obtained/pending (**clause 1.8**)

o) Monitoring personnel Curriculum Vitae (experience/qualification) and availability, where changes are proposed from those submitted at the time of tender

p) CDM risk assessments and emergency/safety provisions

q) Proposals for on site office and storage facilities

Where possible information need not be duplicated for subsequent Works Package Plans but the Contractor shall ensure that adequate cross-referencing to the first Works Package Plan is included.

2.5 Instrument Readings and Recording

2.5.1 General

The Contractor shall be responsible for the collection, processing, storage, interpretation, reporting and dissemination of the data obtained from the installed instrumentation.

The Contractor shall employ a database management system to store, manipulate and report the volumes of data anticipated for the works. The system shall be capable of continuous monitoring and rapidly updating graphical plots to facilitate real-time monitoring where required. The system shall be capable of automatically notifying relevant personnel when pre-set limits are exceeded.

The database system shall enable remote interrogation via internet/extranet access and permit data to be exported to standard spreadsheet software packages for analysis. The data available on the internet/extranet website shall be updated daily. Data shall be stored in a format that is compatible with the Association of Geotechnical Specialists (AGS) data protocol.

All computer data files and calculation sheets used in processing the data shall be preserved until the end of the contract monitoring period. They shall be made available for inspection at the request of the Employer's Representative.

The proposed Instrumentation and Monitoring data management system and its application features shall be demonstrated to the Employer's Representative, and any third parties he considers appropriate, for approval at the start of baseline reading period. The Contractor's full time site staff shall manage the system. A security system shall be incorporated into the data management system so that unauthorised access is not permitted. The management and maintenance of the data management system shall be the responsibility of the Contractor.

The Contractor shall maintain an up-to-date computer virus protection system. All data transmitted to the Employer's Representative or third parties shall be checked for viruses.

The Contractor shall not disclose monitoring data to unauthorised parties or persons and shall not publish monitoring data. Access to the data by third parties shall not be permitted without prior written approval of the Employer's Representative.

2.5.2 Commissioning Readings

After installation of each instrument or array of instruments a commissioning procedure shall be undertaken to demonstrate that the instrument or array is functioning properly including the ability to record measured values using the appropriate readout device. As part of the commissioning procedure three independent sets of readings shall be taken, immediately after installation, such that the results are not significantly affected by temporal variations.

If the three sets of readings are found to differ significantly from each other, the instrumentation shall be checked for adequacy of installation and calibration. A further set of three readings shall then be taken. If the instrument(s) are still giving unreliable data they shall be replaced, repaired or re-calibrated as necessary at the Contractor's expense, and commissioning readings repeated until reliable results are obtained.

2.5.3 Baseline readings

When the commissioning readings have been satisfactorily obtained, these shall be averaged to form the first set of baseline readings, representing conditions before construction starts. Baseline readings shall then be taken at the frequencies indicated in **Table 1** until a minimum of 8 weeks readings have been obtained, or until the Employer's Representative is satisfied that the ambient state has been established.

Where there is any indication that cyclical (tidal, diurnal or thermal/weather) effects may influence the readings, this should be identified by taking readings at appropriate frequencies during the baseline readings period. Any external influences which affect the baseline data shall be identified and described in the weekly and installation reports.

2.5.4 Works Readings

The frequency of readings during the works shall not be less than that listed in **Table 1**, unless otherwise directed by the Employer's Representative. When an instrumentation array is within the zone of influence of the works, or as directed by the Employer's Representative, the frequency of readings shall be taken at the higher frequency as shown. When outside the zone of influence of the works routine readings shall be taken at the lower frequencies shown, or as directed by the Employer's Representative.

Whenever sets of data are measured, they shall be compared to previous sets of data. If anomalous readings are present which differ from the expected value, trend or rate of change, they shall be checked to ascertain whether the anomaly is due to a measurement or reduction error. The Contractor shall inform the Employer's Representative and the relevant contractors immediately.

Further readings at closer frequencies shall be taken immediately. If the readings remain persistently anomalous and are not due to error, an investigation shall be carried out to determine the cause and the Main Works Contractor's contingency or action plans shall be initiated.

At each stage of the works where there are significant progress in the main works (for example, demolition of a structural cross-wall in the West Range Buildings), readings shall be taken at a frequency which shall allow trends with time to be clearly identified and evaluated. These readings shall continue until the rate of change in the readings falls off sufficiently to allow a lower frequency to be adopted with confidence that the safety of the Works is not in doubt.

2.5.5 Measurement Records

The measurement records shall contain for each set of readings the following information:

a) Project title, client and name of the Contractor

b) Contract title, site location and monitoring area

c) The date and time of each reading

d) Serial number of reading instrument used

e) The weather at the time of reading (including temperature)

f) The name of the person who made the reading on site and the name of the person who analysed the readings together with their company affiliations

g) Any damage to the instrumentation or difficulties in reading

h) Tables comparing the specified results with any previous readings and with the base readings (e.g. for the survey studs, on the left hand side of the table there should be a list of each of the survey stations together with the base readings. On the top of the table there should be a list of the dates on which surveying was carried out). Tabulated data is not required for the weekly reports

i) Data in fundamental and engineering units and the calibration constants or equations ("gauge factors") that are being applied and the dates they were determined

Columns of numbers shall be clearly labelled together with units. Numbers should not be reported to a greater accuracy than is appropriate. Graph axes should be linear and clearly labelled together with units. The axis scales are to be agreed with Employer's Representative.

Plots or graphs shall cover a limited time period in arrears (generally 3 weeks) such that sufficient detail can be obtained from the most recent data. The actual period of time covered in the graphs shall be adjusted in agreement with the Employer's Representative to provide a clear representation of the data.

For time plots, time shall be the horizontal axis. Critical activities that may affect the readings shall be annotated on the time scale. Where nearby construction activities at the site may have influenced the readings, these shall be noted by the Contractor.

The plots shall be presented in a clear manner using black and white line types and true to scale axes. Excess data shall not be plotted onto one graph. Separate plots shall be produce as appropriate. Individual data points shall be included on line plots to indicate true reading frequency. They shall be omitted only in the interest of clarity and where the frequency of reading is clearly marked on the graph.

2.5.6 Long term Readings

Monitoring shall continue for at least 3 months after permanent structural works are completed and all temporary works offering support against structural collapse (such as arch ties in the Main Trainshed) are removed. After this period, the Employer's Representative will review the monitoring data and determine if an extension of the long-term monitoring period is required prior to de-commissioning of instruments.

2.5.7 Trigger levels

Table 1 provides values of cumulative long-term predicted movements and trigger values for all structures significantly affected by the works. Further trigger levels may be provided by the Employer's Representative as cross-package design information and coordination and construction programme details become available.

2.6 Continuous assessment of building condition

In order to maintain an overall check on the behaviour of listed structures potentially affected by the Phase II works the following works may be instructed by the Employer's Representative.

2.6.1 Level surveys

The Contractor shall carry out an initial survey of the existing level of the building façade to an accuracy of ±1mm. This shall be done by taking precise levels on a common reference mortar course, cornice or window ledge at approximately 5m intervals along the façade. The reference feature shall be the same external feature throughout the survey and shall be chosen such that it is reasonable to assume that the feature was originally built in a horizontal position.

For a mortar course at each location levels shall be taken at the lower edge of the upper brick and the upper edge of the lower brick defining the mortar course and an average calculated. This shall represent the centre of the reference mortar course. Where appropriate levelling locations shall coincide in plan with the existing BRE type studs already installed. This work shall be carried out at the same time as a weekly baseline reading survey and reported in the installation report.

2.6.2 Extensometer readings between BRE type sockets

Precise taping surveys (i.e. using a tape extensometer) shall be carried out between consecutive pairs of BRE type studs along the façade or structure to determine the current separation between studs. Two further commissioning surveys shall be undertaken in the subsequent weeks of the baseline period in order to provide a reference length for the calculation of horizontal strain in the structure during the works.

2.6.3 Visual inspection surveys

Visual inspections will be carried out by suitably qualified personnel. The Contractor shall be responsible for the following:

a) The Contractor shall familiarise himself with the relevant initial condition surveys and undertake a visual inspection to confirm the results.

b) Examine the defects listed in the Condition Surveys on a monthly basis. The frequency of the inspections may be increased in certain areas associated with construction activities as agreed with the Employer's Representative.

c) Monitor the defects listed in the attached schedule (Appendix B). The Contractor shall take initial photographs of the locations listed in the schedule using a camera with suitable flash capability and date/time facility. The contractor may use a digital camera and submit photographs in digital form where suitable resolution can be obtained. These photographs will then be compared against subsequent photographs where required in order to verify observed changes

d) Advise the Employer's Representative of any new defects observed during the course of the survey. Where changes are observed the following information shall be recorded (with reference to LUL engineering documents M3603, M3801, BRE Digest 251[2] and BRE Digest 343[3]):

- record the time, date and external weather conditions on the day the survey was taken;
- describe the nature of any new observed cracking: tensile cracks - rough open cracks; compressive cracks - flakes of brick or plaster and localised crushing; shear cracks - displacement across the crack, or any combination of these;
- describe the nature of re-activation of existing cracking;
- record the direction of taper, change in crack widths and frequency of cracks (any ruler used should accord with the specification in BRE Digest 343);
- monitor changes in crack width and the data tabulated and plots of cumulative dilation/closure versus time presented;
- sketch new or changes in existing crack patterns on scaled elevation sketches using the recommendations of BRE Digest 343;
- Photographs to be taken from the same location and in detail where changes have been observed on known defects;
- record new damage to plaster and paint work;
- note any distortions of door and window frames (doors and windows sticking, cracks in glazing)

e) Provide a brief monthly report on a pro-forma to be agreed with the Employer's Representative.

[2] Building Research Establishment (1995) – BRE Digest 251. Assessment of damage in low-rise buildings
[3] Building Research Establishment (1989) – BRE Digest 343. Simple measuring and monitoring in low rise buildings

The contractor shall provide suitably qualified building surveyors to carry out the inspections. He shall submit CV's of the personnel to be employed with his tender submission and Works Package Plan.

The Contractor shall ensure that the same surveyor carries out the work during the contract. Should this not be possible due to unforeseen circumstances he shall ensure that a substitute surveyor is available who is familiar with the operating practises and observation methods of the incumbent. When replacing the incumbent the Contractor shall ensure that a two-week hand over period is undertaken where both surveyors conduct the survey in parallel to ensure continuity of observations.

Inspections shall commence immediately upon contract award on a weekly basis during the programmed period of the works.

No information contained within the inspection reports shall be disclosed to any other party without the written consent of the Employer's Representative and the Owner.

2.7 Temporary failure of automatic monitoring system

If automatic monitoring fails within any part of a zone of influence, manual monitoring must be undertaken throughout that zone at a frequency to be agreed with the Employer's Representative but not less than daily. The manual monitoring shall continue until the automatic monitoring is re-established and the data from the automatic monitoring is revalidated.

When works are undertaken on night shifts or during the weekend, measures need to be in place in order that any fault to the system is reported to the Contractor representative within 6 hours from the latest readings. If the fault cannot be repaired within reasonable time, manual monitoring will be instructed in the areas where the monitoring system is unable to provide the required readings. Manual readings should replaced automatic monitoring within 24 hours from the latest reading and continue to the frequency agreed with the Employer's Representative.

2.8 Reporting

2.8.1 General

The Employer's Representative shall be kept informed of the works readings and any effects upon existing structures, within 12 hours of the readings being observed, on a daily basis. Where significant changes have occurred the data shall be communicated to the Employer's Representative immediately, in a format that enables its rapid assimilation. The Employer's Representative shall be informed immediately if any Warning or Action Levels are exceeded.

The Contractor shall supply the monitoring data for existing structures to the contractors and provide electronic access to allow this information to be viewed. Monitoring Data, trends, and the need for appropriate actions in response to trigger levels being breached shall be discussed as an agenda item in daily Contractor's site meetings.

When reporting data for individual instrumentation positions the Contractor shall quote the data in engineering units and shall use the referencing system for each point as set out on the specification drawings. Where additional points are required he shall use consecutive numbers which conform to the system established on the drawings.

All reports shall follow the general format and content agreed with the Employer's Representative for the existing installations.

All reports shall be checked by the Contractor for errors prior to submission to the Employer's Representative. All reports submitted shall have a Quality Assurance insert sheet indicating authorship, checker and the approving authority. The sheet shall be signed by these personnel.

Reports shall typically include the items listed below:

a) A QA check cover sheet

b) An executive summary

c) A brief description of the structures being monitored

d) An assessment of diurnal, tidal or seasonal effects upon the structure response. This should include measurements of temperature (°C); wind speed and direction; precipitation type and depth (mm); barometric pressure (mbar) and relative humidity (%) throughout the monitoring period

e) Significant construction events either occurring or just completed, and any events on site which could affect the data

f) Graphs showing specified trigger and action levels and variation in the measured parameter with time. Key dates shall be marked with a brief explanation of their significance. The time scale should be "real", i.e. each day is equal to the same amount of time

g) The occurrence of errors shall be indicated on the graphs. Assessment of the cause of anomalous readings such as reading or data reduction errors, including annotations on plots as appropriate and proposals for correction should also be included

h) Assessment of change in reading instruments upon data obtained

2.8.2 Installation/baseline readings Report

The Contractor shall submit a detailed report within 14 days of taking the final baseline readings for each monitoring area. In addition to the requirements of **clause 2.7.1** these reports shall include the items listed below.

a) A description of the scope of monitoring work and the instrumentation installed including system design; calculated precision; results of any field trials and comparisons between different instrument results

b) A record of commissioning readings taken for each instrument or array and the environmental conditions at the time the readings were taken

c) A complete record of baseline readings taken for each instrument or array and the environmental conditions at the time the readings were taken

d) An assessment of diurnal, tidal or seasonal effects upon the structure response

e) A record of installation difficulties or variations from the specification. Digital photographs of each installed point shall be taken at the time of installation and retained for future reference. Only representative photographs need be included in the reports.

f) As-built drawings at scales to be agreed with the Employer's Representative on A1 size sheets showing the locations and identification of all instruments, including any pre-existing instrumentation installed in previous Phase I and II contracts falling within the monitoring areas defined in the Phase II Contract drawings. As-built drawings shall include the routing of all cabling. Hidden electrical instrumentation shall be identifiable by reference coding and shall be recorded on the As-built drawings. The drawings shall be developed from the specification drawings in digital format to ensure consistency in presentation.

2.8.3 Weekly Reports

The Contractor shall issue a weekly summary report of the preceding weeks readings and a summary of the Main Works Contractors site activities. The weekly report shall also include an assessment of changes in trends of the data related to those activities as well as a summary of the Main Works Contractors temporary works monitoring. The format for inclusion of this data will be agreed with the Employer's Representative and the Main Works Contractors.

Weekly reports shall comprise the principal means of publishing the data and reviewing the effects of the main works upon existing structures. The reports shall cover the period

Monday morning to Sunday evening and shall be identified as “week ending Sunday dd/mm/yy”.

The Contractor shall issue an executive summary of the key points of the weekly report by e-mail by Tuesday morning of each week to a number of people to be identified by the Employer's Representative.

Hard copies of the weekly report shall be issued by hand at a monitoring review meeting to be held on Thursday afternoon if instructed by the Employer's Representative. Any new developments, which have arisen since the report cut-off date (Sunday evening), shall be reported at that meeting.

Two paper copies and an electronic copy of the report shall be issued to the Employer’s Representative’s document controller. Electronic copies shall also be distributed by email to individuals within the Employer’s or other organisations as directed by the Employer’s Representative.

The data shall be presented in a way that enables rapid assimilation of the information. Graphical presentation is preferred. Raw or tabulated processed data shall not be included in the weekly reports but shall be accessible by the Employer's Representative or his representative, and the main works contractors, electronically or in hard copy. The data shall be stored and indexed to facilitate retrieval.

The presentation of the data in the weekly report shall comprise executive summaries of the results for each of the specific structures. Data shall be presented in graphical form.

2.8.4 Weekly report presentation

In addition to the requirements of clause 2.7.1 the weekly reports shall include the information listed below:

a) Construction progress

A construction progress plan shall be included to indicate the extent of demolition and construction operations current to the date of issue of the weekly report. Where appropriate, photographs showing a general view of construction progress shall be presented.

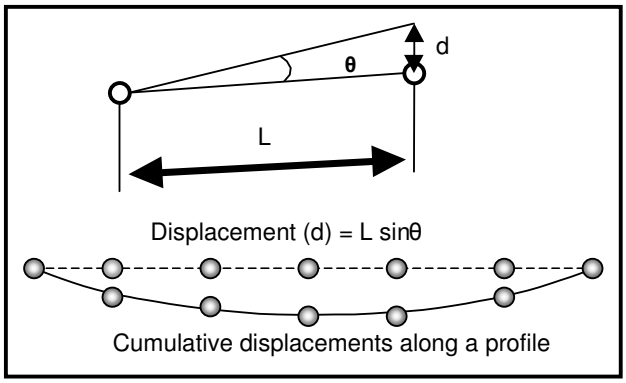
b) Location key plans

An extract location plan showing the location of instruments or arrays for each of the structures or areas being monitored shall be included in the report. The plans shall be legible at the scale at which they are produced in the report.

c) 3-D geodetic monitoring

Movements of building and structures measured in three dimensions shall be presented at scales that provide a clear representation. Data shall be presented in elevation, plan, section or isometric views as appropriate in agreement with the Employer's Representative. Vectors of movement shall be resolved vertically, longitudinally and perpendicular to the building façade. Plots shall show maximum movements for the preceding week at any one instant of time.

Where continuous lines of targets are identified on the monitoring drawings, displacements along a profile shall be processed to give results as ratios of “span/displacement” or “height/displacement” as indicated below. The assumed fixed end points shall be agreed with the Employer's Representative. These data shall be compared against allowable ratios of overall span or height/displacement.



d) Precise levelling of building studs, ground studs and settlement pillars.

Precise levelling data shall be presented as displacement versus time. Contour plots in plan view shall also be presented for each area being monitored, showing the excavation outline and progress.

e) Crack or joint-monitoring

Measurements of movement between studs on three axes shall be used to calculate normal and shear movements after Standing et al (2001)4 – refer to drawing ENG-DWG-OAP-KXS-CGS-0001. Alternatively, where access is remote, "tell-tales" may be used. Data shall be reported as change in length versus time. "Out-of-plane" movements shall also be reported.

f) Strain gauges

When reporting data from surface mounted strain gauges the Contractor shall quote the unique identity and location of the gauge, the results in micro-strain ($\mu\varepsilon$) and the equivalent force in kilo-Newtons (kN) in the element being monitored by calculation from the strain value. The temperature corrections applied shall also be reported.

The input parameters used in the strain gauge equation (datum frequency or period, gauge factor, and conversion factors to $\mu\varepsilon$, etc…) shall be quoted for each gauge in technical data sheets to be included in the Works Package Plans (clause 2.4). Where strain gauge transducers are used in instruments the Contractor shall detail the calibration constants and equations used to convert frequency or period to strain, thence into engineering units in his Works Package Plans. Data shall be presented in engineering units in the weekly reports.

2.8.5 Final Report

Within six months after completion of the main site works the Contractor shall issue a Final Factual Report comprising updated installation records and as-built drawings. The report shall also include a brief summary of the observed movements for each monitoring area or instrument array, relative to the construction works.

The status of the monitoring equipment to be handed over to the Employer's Representative at the end of the Project shall be described fully. Equipment to be de-commissioned shall be listed. The report shall be submitted to the Employer's Representative in both paper and approved digital format.

2.9 De- commissioning Instruments

The Contractor shall remove all instruments, targets, cables, loggers and brackets installed during the Project at the end of the Maintenance Period unless directed by the Employer's Representative to do so sooner or if equipment is to be left in place.

[4] CIRIA SP 200.

The Employer's Representative will notify the Contractor of instrumentation to be left in place at the end of the Project and this will remain the property and responsibility of the Employer's Representative, together with any associated read-out units, loggers, cables and software.

The Contractor shall undertake re-instatement where instruments have been attached to structures. The Contractor shall re-instate structures to a standard that is equivalent or better than indicated by the pre-construction condition surveys.

3 Particular Requirements - Instrumentation

3.1 General

The following clauses give the required technical specifications for instrumentation.

3.2 Precise Levelling "ground" studs

Precise levelling studs shall be installed at locations as shown on the Drawings. A typical detail for ground studs is included in Drawing ENG-DWG-OAP-KXS-CGS-0001. Precise levelling shall be undertaken across these studs to determine the development of settlements of building foundations as a result of changes to the foundation loading due to structural rearrangement.

In high wear areas (roads and pavements for example) the studs shall comprise a stainless steel stud driven or fixed using polyurethane resin in a drilled hole into a hard substrate.

Each stud shall be uniquely identified on the as-built drawings. The detailed design of the studs may be varied to suit the methods and equipment of the Contractor and shall be set out in the Works Package Plan. The design of the studs shall be subject to the approval of the Employer's Representative.

The precise levelling locations shall be surveyed using precise levelling techniques to at least the accuracy/precision stated in **Table 1** and surveyed for plan position to an accuracy of ±25mm.

3.3 Deep datum's

Deep datum pillars shall be installed as necessary to provide reference stations for precise levelling and shallll also have the facility for the temporary attachment of a 3-D geodetic prism to validate the results of the automated theodolite network. The detailed design of the prism mounting may be varied to suit the methods and equipment of the Contractor and shall be set out in the Works Package Plan. Checks on the theodolite network shall be carried out at the Employer's Representative's discretion.

The datum shall be constructed such that it does not interfere with existing services.

The deep datum's shall be surveyed for plan position.

The deep datum's shall be checked for stability on a quarterly basis or more frequently as instructed by the Employer's Representative. A suitable stable reference location (for example the piled walls of the British Library) shall be used subject to the Employer's Representative's approval.

3.4 Precise Levelling Sockets (BRE Type)

Precise levelling sockets shall be installed on buildings as shown on the Drawings. The sockets shall be stainless steel and conform to the manufacturing specification of BRE type A373/52 or similar approved**.** A typical detail for ground studs is included in Drawing ENG-DWG-OAP-KXS-CGS-0001.

A socket shall comprise a stainless steel threaded plug, installed in an approximately horizontal recess, 38mm in diameter drilled approximately 80mm into the masonry/façade. On listed structures the sockets shall wherever possible be installed in mortar joints. In these circumstances a reduced size BRE type socket may be installed in a 25mm diameter hole.

The socket shall be set into the recess using a 1:2.5 cement: sand mortar or an epoxy resin. The hole shall be cleaned using a suitable solvent to remove moisture or grease prior to installing the socket.

Using a loosely inserted Perspex bung into the socket as a handhold, the socket is positioned in the hole so that the front face of it is at least 6mm recessed in the wall. It is important to ensure that the keyway towards the rear of the socket is filled with mortar or resin. Mortar is then tamped firmly all round the socket using a suitable tool, such as a thin steel bar. When the hole is filled to within 2mm of the socket face, the bung is carefully unscrewed and the mortar finished so that it is visibly clear of the socket mating face.

A screw-in de-mountable stainless steel levelling bolt shall be inserted into the socket to enable precise levelling to be carried out. The same bolt shall be used throughout the levelling programme to ensure consistency of results. If the bolt shows evidence of damage (scratching or abrasion for example) it shall be replaced.

A stainless steel bung shall be inserted into the socket when not in use. The bung shall be installed and removed using a special tool such that the bung cannot be removed using a standard set of keys, screwdriver, Allen key or knife. The bung shall be within the recess in its final position and shall be approximately flush with the face of the building.

The precise levelling sockets shall be surveyed using precise levelling techniques to at least the accuracy/precision stated in **Table 1** and surveyed for plan position to an accuracy of ±25mm.

3.5 Building Façade 3-D Geodetic Surveying Prisms

Movements of the building facades and surface structures shall be monitored using geodetic surveying techniques. This shall comprise monitoring of reflective prism targets and resolution of movements into 3 orthogonal axes normal and parallel to the plane of the façade. Locations of prisms on building facades are shown on the drawings. Final target locations shall be agreed on site with the Employer's Representative.

The prisms shall be monitored using an automated programmable theodolite. The theodolite shall be capable of measuring distances to an accuracy of ±1mm + 1ppm and angles to ½ second of arc. The theodolite shall be located not greater than 100metres from the prism locations. Distances greater than this will be acceptable only by agreement with the Employer's Representative.

Wherever possible each reading shall be corrected for diurnal movements at the theodolite location by reference to not less than six stable reference points. The Contractor shall be responsible for installing the stable reference points (and wherever possible the theodolites) outside the zone of influence of the works as agreed with the Employer's Representative. Where necessary vibration monitoring shall be installed to assess potentially erratic readings obtained from the automated theodolite.

Movements shall be monitored continuously at a frequency of at least one reading per hour, depending on the observed rapidity of movements during the baseline period and the construction programme. Variations in reading frequency shall only be made with the Employer's Representative's agreement. Data will be processed and updated immediately it is obtained and shall be available for viewing and interpretation by the Contractor, the Employer's Representative or his representative, or the Main Works Contractors. A software package shall be installed to automatically notify the relevant personnel when trigger levels are exceeded.

3.6 Displacement (Strain) Measurements using Precise Taping

Measurements by precise taping of horizontal displacement between structural elements (walls, columns) may also be required in above ground structures as a direct measure of horizontal strain if instructed by the Employer's Representative.

Precise taping deformation measurements shall be made by measuring with a tape extensometer between anchor points firmly fixed to the structure.

The tape extensometer instrument shall conform to the requirements of the LUL approved "Ealey Extensometer" and record to an accuracy of ±0.05mm for spans of less than 10metres. Details of the Ealey Extensometer may be obtained from the following supplier:

P J Ealey (Engineering)
6 Ghyllside Drive
Hastings
East Sussex
TN34 2NA
Tel: 01424 423 393

The tape extensometer shall be suitable for measuring over the required lengths in any direction from a measuring bolt and have an accuracy/precision as shown in **Table 1**.

Anchor points shall be made from stainless steel and shall be attached to structures by the following methods, subject to the necessary approvals:

- A 21mm outer diameter eyebolt may be used. The bolt shall comprise an 8mm internal diameter loop on a 10mm diameter threaded shank. The bolt shall be screwed into an expanded masonry fixing inserted full length into a 12mm diameter 50mm deep hole. The fixing shall, wherever possible, be fixed into mortar courses and recessed 10mm into the substrate such that the hole may be made good with colour matched mortar when the fixing is no longer required.
- A 20mm outer diameter "hasp and staple" type loop mounted on a plate. The loop shall stand not more than 20mm from the substrate surface and shall be welded onto a 3mm thick 35mm x 30mm base plate. The base plate shall be fixed through 4No. screw holes in each corner to the substrate using security head 30mm length zinc plated screws and rawl plugs. All four screws shall be installed.
- Where BRE type sockets have been installed the contractor shall provide an interchangeable extensometer bolt insert. The tape extensometer attachment shall employ a "universal joint" or similar mechanism[5] to ensure consistent readings.
- Where the above types of fixing are used the fixing shall be proof load tested to 20kg to verify the adequacy of the fixing.

The ambient temperature shall be taken at the time of each reading. The instrument shall be used and read in accordance with the manufacturer's instructions. Three readings shall be taken and recorded for each measurement and averaged prior to making the temperature correction. The instrument shall be checked against a calibration bar before and after each set of readings. Readings on the calibration bar shall be recorded with the field readings. Instruments failing to show consistent readings on the calibration bar shall be repaired or replaced.

The temperature of the tape extensometer and calibration bar shall be allowed to stabilise to the ambient temperature of the measurement location prior to taking readings.

When locating the instrument onto the measuring bolts care shall be taken to ensure the surfaces are clean.

Temperature corrections shall be made to the readings using the coefficient of linear expansion provided by the manufacturer for the tape in use.

If a measurement line becomes unavailable, for example when permanent services are installed, dual readings shall be taken with its replacement. If due to construction work this is impossible, then readings shall be taken on the old line at the latest possible time and the new line shall be established and read as soon as possible.

[5] After Burland and Moore (1973): BRE CP 26/73; and Standing et al (2001): CIRIA SP 200.

3.7 Beam Electrolevels

Beam electrolevels shall be installed in if instructed by the Employer's Representative.

Each electrolevel assembly shall be supplied by a specialist instrument manufacturer with a proven capability in structural monitoring.

Each electrolevel assembly shall be calibrated prior to installation. The calibration shall be carried out across the full range of measurement at a temperature within +/-5°C of that at the intended location. Where installations are likely to be subjected to daily or shorter term, temperature fluctuations of greater than +/-5°C the electrolevel sensor shall be equipped with a built-in thermocouple. The thermocouple readings shall be recorded at the same time as the electrolevel and shall be used to correct the calibration of the electrolevel.

Beams onto which electrolevel assemblies are mounted shall be manufactured from Dural HE30 or similar material. Fixings shall be manufactured from stainless steel. The beams and fixings shall be sufficiently rigid that the deflection of the whole installation under self-weight does not exceed 0.5mm. The fixing arrangement shall not restrain the expansion or contraction of the beam and/or the structure to which the beam is attached.

Electrolevels shall be provided with cabling, loggers and read-out units to enable them to operate and be interrogated by electronic data loggers without direct access. Cable lengths from each electrolevel to a data logger shall be kept to a minimum. Electrolevel calibrations shall be adjusted for cable lengths in excess of 20m.

Data loggers shall be capable of recording at the time intervals and in the order specified. The frequency of readings (excluding over-sampling) shall not be less than 30s unless otherwise directed by the Employer's Representative.

The accuracy of the electrolevel assembly shall be 20 second of arc or better over a range of measurement of at least 3 degrees. The whole installation of beams, fixings and the associated data loggers shall have an accuracy of 0.1mm in horizontal and vertical deflection.

3.8 Tiltmeters

The change in inclination of surface structures such as building facades shall be measured using electrolevel tilt sensors securely fixed to the structural elements. Tiltmeters shall be of the biaxial type, with heated vials to correct for external temperature variations.

Installation of tiltmeters on existing structures will be advised by the Employer's Representative as required. The Contractor shall also supply cabling, data-loggers, read-out units or radio transmitters as required.

Movements of the structures shall be determined both normal and parallel to the plane of the structure in accordance with **clause 3.10**. The required accuracy of the tiltmeters is stated in **Table 1**.

3.9 Crack Deformation Monitoring

3.9.1 Calliper studs

Dilation of existing cracks or construction joints shall be monitored using a calliper reading to a precision of better than ± 0.1mm.

The calliper shall be used to record the overall distance between the barrels of a pair of flat 6.2mm diameter stainless steel studs securely bonded to the surface. The studs shall be bonded using a rapid setting epoxy resin, which shall not be subject to creep. There shall be no movement of the studs when installed. Alternatively screws may be installed to the specification given in BRE Digest 343.

Studs shall be fixed in an equilateral triangular pattern, at a spacing governed by the gauge of the instrument. The studs shall be arranged as shown in drawing ENG-DWG-OAP-KXS-

CGS-0001 and displacements determined as shown. The lengths of all sides of the triangle are measured.

"Out-of-plane" movements shall be monitored using a steel rule and straight edge as described in BRE Digest 343. Such movements shall be measured to ±0.5mm resolution.

3.9.2 Tell tales

Where a defect to be monitored is at high level or difficult to access, a "tell-tale" device may be used. The tell-tale shall comprise plastic plates screwed to the façade either side of a defect marked with a cursor and graduated scale marked on.

Tell-tales shall be monitored remotely using theodolites or similar telescopic instruments for movements normal, parallel and perpendicular to the façade to an accuracy of ±1mm.

The tell-tales shall be weather resistant and remain readable for the duration of the project.

Tell-tales shall not be used in publicly accessible locations where access from ground level is possible. Fixed glass tell-tales shall not be used.

3.10 Vibrating Wire (VW) strain gauges

Strain gauges shall be installed on temporary ties across the Main Trainshed arches as shown on drawing ENG-DWG-OAP-KXS-CGS-0002.

Strain gauges shall be installed prior to preloading the ties. The ties shall be preloaded using a calibrated jacking system that allows the preload force to be determined so that the baseline reading of the VW strain gauge can be related to a known force in the tie. Jack pre-load, the associated VW strain gauge reading and all relevant ambient condition readings shall be recorded as per section 2.5.5. Where the performance specification for the ties does not specifically require preloading the ties shall be preloaded to at least 10% of their design capacity in order to ensure that baseline readings for the VW strain gauges are recorded. The contractor shall develop this procedure for determining baseline strain gauge readings in detail and submit these to the Employer's Representative for acceptance.

Vibrating wire strain gauges shall be of robust construction. All exposed parts of the gauge shall be manufactured from stainless steel grade 316 S13 of BS970: Part 1. Those not designated on the Drawings as waterproof, shall be splash proof. Those designated as waterproof shall be tested to withstand a test pressure of 15 bars prior to delivery to site. Test Certificates shall be provided.

VW strain gauges shall be provided to the gauge lengths specified on the Drawings and have the characteristics set out below. The calibration characteristics of each gauge shall be obtained from the manufacturer.

- Strain range: 2500 x 10- 6 mm/m
- Accuracy: ± 3 x 10-6 m/m
- Resolution: 0.5 x 10-6 m/m
- Operating temperature range: -10℃ to +40℃

Fixing of VW strain gauges shall be undertaken as follows:

a) Any coatings on the substrate shall be removed and the surface ground smooth. The prepared surface shall be clean, dry and free from grease.

b) A hard type of rapid setting epoxy adhesive compound which shall not creep under the applied loading shall be used to fix the gauge and to compensate for any curvature of the substrate. It is essential that during fixing the gauge is not distorted and its operation impaired.

c) Cabling from the gauges shall be firmly attached to the substrate and terminate in a local terminal box. The Contractor shall also supply cabling, data-loggers, read-out units or radio transmitters as required.

d) VW strain gauges fixed steelwork in exposed locations shall be enclosed in protective boxes of robust fully welded, watertight, construction and made from stainless steel sheeting. The box is to be sized such that 15mm clearance is provided to any part of the enclosed gauge or gauges. The boxes shall be provided with flanges which shall be fixed to the substrate. A neoprene gasket shall be fixed between the substrate and the flange. As added protection against the ingress of water, soil or grout the box and a surrounding 25mm band is to be liberally coated with a bitumastic compound.

3.11 Strain gauge joint-metres

Where employed, joint metres shall be of the vibrating wire strain gauge type, capable of measuring strains in three orthogonal axes. The instrument shall have a range of ±25mm, shall be capable of 0.025% resolution over 25% of the range, and precision ±0.1% of the range.

The instrument shall be capable of being read remotely and in “real-time”. The Contractor shall supply cabling, data-loggers, read-out units or radio transmitters as required.

The instrument shall have built in thermistors for temperature monitoring and correction.

3.12 Vibration Monitoring

Where an automated theodolite may be affected by train or traffic, vibration sensors shall be installed to assess the potential effect on readings.

The instruments shall be capable of measuring or deriving peak particle velocity and particle velocities in three orthogonal axes; displacement; acceleration and vibration frequency.

3.13 Remote Readout Facilities

3.13.1 Instrument Cabling

All cabling for the instrumentation shall be robust, resistant to penetration and water ingress. Where cable is to be installed above ground on an exposed surface it shall be housed in protective PVC conduit firmly fixed to the substrate. Where cable passes over an area where movement and strain of the cable may arise it shall be looped where practicable to do so.

In-tunnel cabling shall not corrode, shall be screened, halon free “low smoke” cable and shall comply with relevant LUL standards. Cabling for the instrumentation shall be run in earthed steel conduit or securely tied to earthed steel cable trays, which comply with relevant LUL standards. Conduit or cable trays shall be securely fixed to the tunnel linings. Alternatively, fibre optic communications cable may be used subject to the Employer's Representative's approval.

Leads from individual instruments, or connections from local terminal boxes, shall terminate in readout boxes to which a portable reading device or a remote down loading facility can be attached. All cable entries to the boxes shall be through watertight glands. The terminals in the readout boxes are to be clearly marked with the relevant instrument reference number on engraved plastic laminated name plates.

3.13.2 Readout units

All electrical measuring devices shall be capable of being read remotely from portable remote readout units. The readout units and the appropriate plug-in leads shall be supplied by the Contractor and shall be compatible with the instruments being monitored.

Readout boxes (multiplexers) shall collect the cabling from the various remotely read instruments and from local terminal boxes so that monitoring can be conveniently carried out from a single position close to the instrumented arrays. The input cable shall be clearly marked with its associated output channel/instrument identification.

Readout devices shall have facility for recording monitoring data digitally. Readout boxes shall be capable of being placed up to 200m from their associated transducers with the specified accuracy of the instrumentation maintained.

Terminal and readout boxes shall be of robust, water resistant, corrosion proof construction. Cable connections in terminal boxes placed in tunnel inverts shall be made waterproof by the use of suitable cable enclosures and cable glands to the satisfaction of the Employer's Representative.

Readout terminal panels shall be located in areas not subject to the effects of traffic. Vibration monitoring shall be carried out where traffic vibrations are suspected of affected the readings obtained.

The readout boxes shall have lockable sealed doors.

3.13.3 Radio relays

Radio relays to transmit data to the Contractor control room shall be above ground. Hard wired connections conforming to **clause 3.18.1 and 3.18.3** shall be used between the radio relay and read-out units.

In addition, the installed systems shall have the appropriate approvals. These will include:

- Radio frequency license – the Contractor shall ensure that the Radio Licensing Board and BT Police approve the frequency used for data transmission.
- Operating frequency: a frequency of 2.4GHz is used nationally for local area networks (LAN's). However where a number of other users are nearby excessive interference may results in loss of data transmission. The Contractor shall ensure that a suitable frequency is available throughout the duration of the project.
- Approval of the owner of building upon which the antennae are situated

TABLES

Table 1 Long-Term Predictions, Trigger Values and Monitoring Frequencies

Structure and drawing reference No.	Type of Instrument	Measurement	Reading Method	Accuracy or Precision (mm)	Maximum predicted movement	Trigger Levels		Minimum Monitoring Frequencies		
						Warning Level	Action Level	Baseline readings and/or Works Readings in zone of influence [1]	Works readings outside zone of influence [2]	Long term readings [3]
Kings Cross Western Range Building ENG-DWG-OAP-KX6-CGS-0002	3-D prisms	x, y, z displacement.	Automated theodolite	±1.0mm + 1ppm (0.5" arc)	15mm In/out movement of façade	10mm	15mm	hourly	2-hourly	4-hourly
					Span/500 or Height/500 for distortion along identified lines of prisms [5]	Span/1000 or height/1000	Span/500 or height/500			
	Extensometers between BRE sockets (as instructed by Employer's Representative) [4]	In plane horizontal strain	Precise taping	±0.05mm				Three sets of commissioning readings during baseline period then at ER's instruction.		
	Precise levelling as instructed by Employer's Representative	Vertical displacement	Precise levelling	±0.5mm				Commissioning reading during baseline period then at ER's instruction.		
	BRE type levelling sockets	Vertical displacement	Precise levelling	±0.5mm	-15mm	-10mm	-15mm	weekly	2-weekly	monthly
	Tell Tales	Local displacement of construction joints or cracks	Visual	±1mm	n/a	3mm	5mm			
	Crack monitoring studs (from condition surveys)		Callipers	±0.1mm						
Kings Cross Suburban Train Shed ENG-DWG-OAP-KX6-CGS-0001	3-D prisms	x, y, z displacement.	Automated theodolite	±1.0mm + 1ppm (0.5" arc)	15mm In/out movement of façade	10mm	15mm	hourly	2-hourly	4-hourly
					Span/500 or Height/500 for distortion along identified lines of prisms [5]	Span/1000 or height/1000	Span/500 or height/500			
	BRE type levelling sockets	Vertical displacement	Precise levelling	±0.5mm				weekly	2-weekly	monthly
	Crack monitoring studs (from condition surveys)	Local displacement of construction joints or cracks	Callipers	±0.1mm	n/a	3mm	5mm			
	Tell Tales		Visual	±1mm						
Kings Cross Train Shed (internal) ENG-DWG-OAP-KX6-CGS-0002	3-D prisms	x, y, z displacement.	Automated theodolite	±1.0mm + 1ppm (0.5" arc)	15mm In/out movement of façade	10mm	15mm	hourly	2-hourly	4-hourly
					Span/500 or Height/500 for distortion along identified lines of prisms [5]	Span/1000 or height/1000	Span/500 or height/500			
	Extensometers between BRE sockets (as instructed by Employer's Representative)	In plane horizontal strain	Precise taping	±0.05mm				Three sets of commissioning readings during baseline period then at Employer's Representatives instruction.		
	Levelling studs and BRE type levelling sockets	Vertical displacement of columns supporting arch roof	Precise levelling	±0.5mm				weekly	2-weekly	monthly
	Vibrating wire strain gauges	Local strain in roof arches	Data logger	±3 micro-strain	Design stress levels to be advised by tie specifier (Pk 2)	75% of design stress	100% of design stress	continuous		
	Tell Tales	Local displacement of construction joints or cracks in columns or walls	Visual	±0.1mm	n/a	3mm	5mm	weekly	2-weekly	monthly
	Crack monitoring studs (from condition surveys)		Callipers	±0.1mm						

Structure and drawing reference No.	Type of Instrument	Measurement	Reading Method	Accuracy or Precision (mm)	Maximum predicted movement	Trigger Levels		Minimum Monitoring Frequencies		
						Warning Level	Action Level	Baseline readings and/or Works Readings in zone of influence [1]	Works readings outside zone of influence [2]	Long term readings [3]
Kings Cross South - (Clock tower façade) ENG-DWG-OAP-KX6-CGS-0002	3-D prisms	x, y, z displacement.	Automated theodolite	±1.0mm + 1ppm (0.5" arc)	15mm In/out movement of façade	10mm	15mm	hourly	2-hourly	4-hourly
					Span/500 or Height/500 for distortion along identified lines of prisms [5]	Span/1000 or height/1000	Span/500 or height/500			
	BRE type levelling sockets	Vertical displacement	Precise levelling	±0.5mm	Span/500 for distribution along identified lines of studs	Span/1000	Span/500	weekly	2-weekly	monthly
	Crack monitoring studs (from condition surveys)	Local displacement of construction joints or cracks	Callipers	±0.1mm	n/a	3mm	5mm			
	Tell Tales		Visual	±1mm						

Notes

[1] Baseline readings are to be taken for a minimum period of 8-weeks at the frequencies shown. Works readings (in the zone of influence) shall be taken for the duration of the construction operations where these are likely to influence the monitored structure. The Contractor shall seek agreement with the Employer's Representative when this phase of monitoring commences.

[2] Works readings outside the zone of influence shall be taken for typically one month, and the Contractor shall seek agreement with the Employer's Representative when this phase of monitoring commences.

[3] Long term monitoring shall be carried out over a minimum of 3 months at the frequencies shown. The Contractor shall seek agreement with the Employer's Representative when this phase of monitoring commences

[4] Measurements of horizontal extension using precise taping will be instructed by the Employer's Representative. Commissioning readings will be required.

[5] Permissible distortion to be checked against structure profile surveys prior to start of works

Appendix A

Schedule of Condition Survey Reports

Number	Title
67050/90/24	Condition Survey of South Wall Including Towers
67050/90/24-1	Condition Survey of South Wall Including Towers - Additional Observations
67050/90/102	Condition Survey of Western Range West Elevation
67050/90/104	Condition Survey of Building at South End Of Platforms 9 To 11
67050/90/105	Condition Survey of Internal Area Of Western Range Building
67050/90/109	Condition Survey of the Basement Service Corridor of the Western Range Building.
67050/90/116	Condition Survey of Western Range East Elevation
67050/90/117	Condition Survey of Roof to Western Range Building and West Side Offices
67050/90/129	Condition and Photographic Survey of Selected Windows of the Western Range Building.
67050/90/131	Condition Survey of Spine Wall
67050/90/138	Condition Survey of Main Train Shed Roof
67050/90/171	Condition Survey of Western Range South Elevation

Appendix B

Schedule of Defect Monitoring

B1 Schedule of Defect Monitoring

This schedule is to be reviewed and updated once structural and fabric surveys are completed and reviewed. The Contractor shall add significant defects detected during opening-up works as construction progresses.

Western Façade of the Western Range

Defect 04 – tell tale

Defect 05 – tell tale

Defect 10 – tell tale

Defect 13 – calliper studs

Defect 24 – calliper studs

Defect 38 – tell tale

Defect 42 – 2 sets of tell tale

Defect 45 – calliper studs

Defect D09/10 – tell tale

Southern Façade of Western Range Building

Defect 2 – calliper studs

Defect 3 – calliper studs

Defect 4 – calliper studs

Suburban Train Shed

Defect P9&11/52A – calliper studs

Defect P9&11/52B – calliper studs

Spine Wall

Defect SPW/AG/01 – calliper studs

Defect SPW/08 – calliper studs

Defect SPW/09/01 – calliper studs

Defect SPW/09/02 – calliper studs

Defect SPW/11 – calliper studs

South Wall of Kings' Cross Station

SW/04

SW/06

SW/12

SW/28