bulletin 37

Precast concrete railway track systems

state-of-art report

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State-of-art report prepared by

Task Group 6.5

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Foreword

The use of concrete sleepers started in the 19th century, when a few reinforced concrete sleepers and stone block sleepers were used. However it was not until the early 1940's, when there was a need for a substitute to timber, that the real development of concrete sleepers began.

In 1986, the FIP Commission on Prefabrication, keen to promote the development of all the precast structural concrete products, issued the state-of-art report "Concrete Railway Sleepers", which included design considerations, manufacturing methods, rail fastening systems and field performance.

During the two decades since that report, precast concrete has gained more and more importance in the field of railway track systems for plain track, switches and crossings, tunnels and other applications. Precast concrete is the best performing and invariably the preferred choice and represents a very significant application within the industry of prefabrication.

Although in some countries the ownership of the railways has changed, railway companies remain very large organisations. They are responsible for stating their requirements and specifications and they generally work closely with the precast concrete manufacturers in research and development projects.

Some unification towards standard specifications has taken place, namely within Europe. Certainly all aspects of precast concrete railway track systems, from design through manufacture to installation and maintenance have progressed. Thus, an update of the FIP state-of-art report was considered timely.

The *fib* Commission 6 "Prefabrication", successor to the former one, is issuing this new report, which is believed to provide a good synthesis of currently available information on precast concrete railway track systems, thanks to the work of Task Group 6.5, chaired by Tony Darroch, UK.

Marco Menegotto
Chairman
fib Commission 6

Contents

1 Introduction

In 1987 the FIP Commission on Prefabrication published a state-of-the-art report on concrete railway sleepers. In response to the many changes and developments in the industry and by manufacturers this report has now been updated.

The railway industry and the rail product manufacturing industry have both become increasingly competitive. Engineers are under increased commercial pressures while still having to meet their high engineering standards. The privatisation of some railway companies has added to the pressures exerted on today's engineers.

The rail product manufacturing industry has responded in many ways. New quality management systems have been introduced, relieving the need for external inspections and ensuring the customer receives quality products and service to meet specification. Increased axle loads and speeds on the railways have led to new designs and products being introduced to meet the needs of the railway. Solutions are available to minimise noise and vibration. New designs of rail fastenings with high elasticity, that are now pre-assembled onto the sleeper prior to delivery, and the almost universal adoption of heavy continuously welded rail (CWR) and good hard wearing ballast have all led to significant reductions in overall track installation and maintenance costs.

Developments in production methods for concrete sleepers in switch and crossing layouts to cope with the complex geometry and the industry's confidence in their performance has led to a huge increase in the use of this type of sleeper. The use of slab track for high-speed track has also grown, particularly where either new track is built or where existing track is renewed and long periods of track possession are possible.

There has been progress in the development of plant and equipment for the installation, renewal and maintenance of concrete sleepered track. With machines now able to replace existing track at a rate of 5000 sleepers (over 3 km track) per day, choosing concrete sleepers can reduce the time on site, meaning tracks can be reopened quickly whilst reducing labour requirements and costs.

In the early 1980's, in some countries, the concrete rail product manufacturing industry suffered from the problems encountered in the wider concrete industry. These problems included premature deterioration of products through Alkali Aggregate Reaction (AAR) or Alkali Silica Reaction (ASR) and delayed ettringite (DEF). Since then, manufacturers have worked hard to ensure these problems do not occur in concrete track products. New codes of practice and specifications have been introduced covering all aspects of railway products from design to installation and maintenance. Strict regulations govern the selection of aggregates and cement and the control of the temperature of the concrete.

In many countries timber sleepers have been used extensively, however environmental and financial pressures and availability have led to the increasing use of concrete sleepers.

Sleepers manufactured from other materials including steel, plastic, and other composites have been developed and used on a small scale but concrete sleepers remain the railway engineer's first choice because of their technical superiority when considering:

- long-term durability;
- improved geometric retention of track and greater weight vital for high-speed and heavy freight lines;
- improved elasticity of track;
- improved ride quality;
- low first cost;
- minimum life cycle cost;
- low cost of maintenance;
- environmentally friendly – no chemical treatment required and can be recycled.

2 Description of precast concrete track systems

2.1 General

There are two main types of track system generally known as ballasted track and non-ballasted track.

In ballasted track the rails provide the running surface for the rolling stock, absorbing all the vertical and horizontal forces and redirecting them into the sleepers on which they are fastened. The sleepers in turn direct these forces into the ballast and subgrade layers.

In non-ballasted track the ballast is replaced by a concrete roadway that can be constructed by a combination of precast and insitu concrete.

2.2 Ballasted track

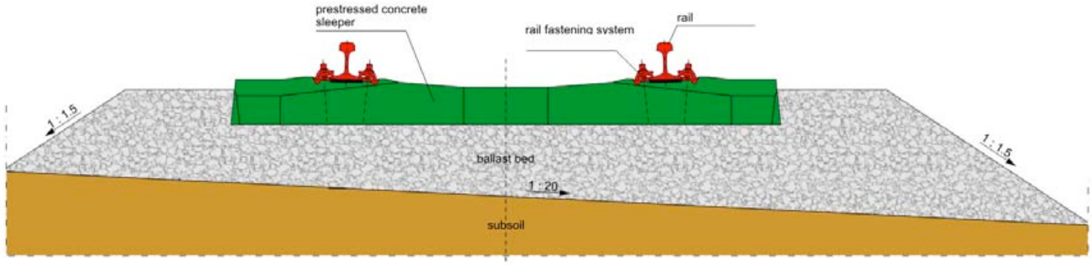

Figure 2-1: Ballasted track

Although there are reports of concrete sleepers first being manufactured at the end of the 19th century, their introduction started at the end of the Second World War. Hitherto timber sleepers had been exclusively used but the shortage of good quality timber at this time prompted the use of concrete sleepers, which rapidly became the preferred type because of their technical superiority. Designs and rail fastening systems have been developed and ballasted track systems provide the vast majority of track in use today.

There are two main types of sleeper – the reinforced twin block sleeper and the prestressed monoblock sleeper. Twin block sleepers are used extensively, particularly in France, on standard lines for 25 tonne axle loads up to 200 km/hour and on TGV lines for 17 tonne axle loads and 300 km/hour. Monoblock sleepers are used extensively throughout the world and are in use for all line types including high-speed lines and for heavy haul lines with axle loads up to 35 tonnes.

Figure 2-2: Twin block sleepers, Channel Tunnel Rail Link, UK (2005)

Concrete monoblock turnout sleepers for switch and crossings on ballasted track are now used in most countries. The detailing and manufacture of these sleepers is far more complex than for ordinary sleepers because the position of the fastening system for the diverging track changes for each sleeper.

Figure 2-3: Trial assembly of crossover before installation, Balfour Beatty Rail Products, Sandiacre, UK (2004)

2.3 Non-ballasted track

This form of track is normally referred to as slab track and its initial use began in the mid 1960's. The slab is a continuous concrete pavement and the types most commonly used are:

- fixed sleepers with insitu concrete;
- elastically support sleepers in insitu concrete e.g. twin or single block sleepers in rubber boots;
- precast slab segments;
- insitu concrete.

Some of the advantages of this track system compared with ballasted track are:

- reduction in construction depth,
- lower maintenance requirements and costs, therefore greater operating availability,
- no ballast cleaning or renewal,
- increased service life,
- high lateral track resistance;
- no problems with high speed ballast particle churning;
- mitigation of ground borne vibration.

These advantages have to be evaluated considering:

- higher initial investment;
- slightly greater noise levels due to no ballast to absorb the noise;
- greater problems and costs in rectifying track if any subgrade settlement occurs – the rigid slab can deteriorate and crack;
- greater difficulty and cost rectifying track damage after derailment;
- longer construction time.

Slab track is therefore particularly suitable for tunnels and may, in the construction of new tunnels, allow a narrowing of the tunnel cross-section and reduction in construction costs. Slab track is also suitable for bridges. It has been in use on high-speed lines for many years, particularly in Japan, but even there conventional ballasted track is still used on more than 90% of the track. It is not so suitable for the renewal of existing lines because of the longer possession times and the subsequent long periods of non-operational train running.

A more recent development has been the use of concrete sleepers on an asphalt layer and connected to it by anchorages. Special asphalt mixes have been developed to provide a 50 to 60 year life and as it can be subject to loading immediately after cooling installation times are reduced.

Figure 2-4: Slab track in tunnel, Reseau Ferre de France, Marseille tunnel high speed line (2003)

3 Quality assurance and testing

3.1 Quality assurance

There has been much progress in the effectiveness of quality management systems over the last 20 years and the concrete sleeper industry has been proactive in developing and implementing quality management in accordance with ISO 9001. Nowadays quality management systems are embraced by whole management teams and cover all aspects of the organisation.

Quality management systems should demonstrate a manufacturer's ability to consistently provide the product and service that meets the customer and applicable regulatory requirements, and through application and continual improvement of the system, give assurance of conformity with those requirements.

The implementation of a quality management system guarantees that:

- All processes needed for the quality management system have been identified and methods introduced to monitor, measure and analyse these processes. Actions will have been implemented to achieve planned results and continual improvement.
- Documentation shall include quality policy, quality objectives, a quality manual, and any procedures required by the system. Documentation will also include procedures for effective planning, operation and control of its processes.
- The quality manual shall detail the scope of the quality management system, the procedures established for the system and any interaction between them.
- Records will be established and maintained to provide evidence of conformity to the requirements and operation of the quality management system.
- Senior management will show commitment to the development and implementation of the quality management system. They should also strive to continually improve its effectiveness by ensuring quality objectives are met through formal reviews and by communicating with the work force the importance of customer satisfaction.
- Quality objectives are established in all relevant functions and levels within the company.
- The quality management system will be reviewed by senior management at planned intervals to ensure its continuing suitability, effectiveness and adequacy. The reviews should include the review of audits, customer feedback, process performance and product conformity, the status of preventive and corrective actions and any recommendations for improvement.
- All personnel performing work that could affect product quality shall be competent on the basis of appropriate education, training, skills and experience. The personnel must be made aware of the relevance and importance of their activities and their contribution to the achievement of the quality objectives.
- The quality objectives of the product have been established and records must be maintained to provide evidence that the verification, validation, monitoring, inspection and test activities specific to the product acceptance are carried out. A document specifying the processes of the quality management system, sometimes referred to as the quality plan, is shown in Appendix 1.
- Effective arrangements for communicating with the customer should be determined and implemented.
- Procedures are established to ensure that all purchased materials conform to the relevant purchase requirements. Suppliers should be evaluated and selected upon their ability to supply in accordance with the requirements. Criteria for selection

evaluation should be established and records maintained of all evaluations. Inspection and testing procedures should be established to ensure the purchased products meet the purchase requirements.

- Production should be planned and carried out under controlled conditions, which should include all work instructions, the use of suitable manufacturing equipment, monitoring and measuring devices and testing equipment.
- The final product should have means of unique identification and there should be complete traceability of all the processes and purchased material used for that product.
- The monitoring and measuring equipment used to provide evidence of conformity of the product will have been calibrated or verified at specified intervals.
- There should be a means of measuring customer satisfaction.
- Non-conforming product will be identified to prevent its unintended use or delivery.

3.2 Testing

3.2.1 General

Testing of materials and finished product can be conducted either by the manufacturer or an approved third party agency. In the case of some materials, for example cement and steel, the suppliers can perform the testing, providing they operate an approved quality management system and supply all the relevant test data before the materials are used.

3.2.2 Design qualification testing

A number of sleepers are manufactured for qualification testing. The materials used and the final product should be inspected and tested to verify conformity with the design and specification requirements. In addition to the strength of the concrete, special care must be taken to ensure durability. Material testing should include the petrographic analysis of aggregates to ensure that when used with cement, the alkali content of the cement does not react with the aggregate. Strict rules exist to avoid the risk of alkali silica reaction.

Abrasion resistance of the aggregates should be tested so that abrasion of the product by the ballast is minimised. The hardened concrete should be tested for porosity and for freeze thaw resistance in those countries with low temperatures.

In addition to checking that all dimensions of the finished product are within their permitted tolerance range, load testing should be carried out on a number of sleepers. This testing should include a bending load test at the rail seat and when applicable at the centre of the sleeper. It is normal that both static and repeated dynamic tests are done. Each test is normally in three parts: the first to establish that the design load is met; secondly that when the design load is exceeded by a specified factor, cracking of the product is such that that the product remains serviceable; thirdly that the design load is exceeded by a specified factor when failure occurs.

Qualification is also required for the rail fastening system used.

Figure 3-1: Dynamic testing of sleeper

3.2.3 Routine testing and inspection

Regular testing of all materials is carried out at a planned frequency to ensure continual compliance with the design and specification requirements. Those tests required for design approval are repeated if there is any change in the supply source of the materials.

The manufacturing process and the storage of the finished product are inspected and controlled at every stage. For example, to avoid the durability of the concrete being adversely affected by the formation of delayed ettringite, the curing of the concrete should be monitored to ensure that: no accelerated curing is applied before the concrete has reached it’s initial set; the rate of gain of temperature of the concrete is maintained within prescribed limits and the maximum temperature prescribed is not exceeded. The specification details these limits.

A minimum specified percentage of all the products made should be dimensionally checked. Static bending load tests, normally at the rail seat are carried out to ensure continual compliance with the specification.

Final inspections must also be carried out prior to the despatch of the product.

Most companies have adopted the widespread use of computers usually connected to a central company network. This allows all personnel to have instant access to all the documents within the quality management system. The use of electronic digital gauges and equipment allows the results of product gauging, load testing, and concrete curing temperatures to be downloaded immediately to provide a continually up to date record so that adverse trends can be arrested before they result in a non-conforming product. Indeed computerised systems can automatically control the whole of the curing process including preset start times, rate of gain and absolute temperatures recording the actual times and temperatures achieved.

4 Sleeper production systems

4.1 General

There are many factors a manufacturer considers when setting up a new manufacturing system to ensure that the sleepers are produced at the most economical cost and these include:

- Total number of sleepers required
- Number of different types of sleeper required
- Time from order to commencement of supply
- Duration of supply period
- Availability of skilled labour
- Degree of automation
- Length of working day
- Climatic conditions
- Health and safety requirements
- Amount of initial investment available
- Labour and production costs

All production systems can be designed with varying levels of automation and labour requirements. Accelerated curing of the concrete by the introduction of heat can be used to achieve high early strengths. Great care must be taken to ensure the heat is not introduced before the concrete has reached its initial set, and then only at a rate where the rate of gain of concrete temperature and its maximum temperature does not exceed strict limits.

For some systems very dry concrete is used and the sleepers are removed from their moulds onto a pallet immediately after the concrete has been placed and compacted. These instant, de-mould systems produce sleepers with a surface finish which is less smooth than that achieved for late de-mould systems but the concrete is equally durable.

There are two main sleeper types, pre-stressed sleepers and reinforced concrete sleepers.

There are two types of pre-stressed sleeper, pre-tensioned and post-tensioned sleepers.

For pre-tensioned sleepers the load in the pre-stressing tendons is applied prior to casting. When the concrete has reached it's required strength the load in the tendons is released and the tendons maintain the load through the bond of the concrete placing the concrete under stress.

For post-tensioned sleepers the load in the tendons is applied after the concrete has been placed and has reached the required strength. The tendons are anchored at the ends of the sleeper by mechanical anchorages, usually threaded tendons with nuts and plates, placing the concrete under stress.

4.2 Pre-tensioned sleepers

There are three main categories of production systems for pre-tensioned sleepers

- long line systems usually from 20 to 80 sleepers in length
  (type e in Appendix 3)
- short-line systems from 2 to 8 sleepers in length
  (type d in Appendix 3)
- single mould systems
  (type c in Appendix 3)

4.2.1 Long-line system

Each mould, which can have several sleepers side by side, is placed in a production line end to end. Normally there are no more than 8 sleepers per mould and the production lines are 20 to 80 moulds long. High-grade pre-stressing steel tendons made up of either single or stranded wires are tensioned to the required load and anchored at each end of the line in large jackheads. Concrete is placed and fully compacted in the moulds and heat can be introduced to accelerate the rate of gain of concrete strength. After a suitable curing period and when the concrete has reached a minimum strength, the pre-stressing tendons are released and the force in the tendons is maintained by the bond with the concrete. The tendons can be indented to maximise the bond between the tendon and the concrete. The tendons are cut at each end of the sleeper either before or after removing them from their moulds and the sleepers are inspected, tested and placed into storage.

This method is often used for long-term production of standard sleepers at a reasonably constant daily rate. Overall production cycle times are normally 24 hours but with the use of specially designed concrete mixes with additives and very controlled heat curing it is possible to reduce this time to 12 hours.

4.2.2 Short line systems

Normally up to 4 sleepers are cast side by side in each mould and up to 8 moulds are placed end to end built into a steel-pre-stressing frame. This frame anchors the pre-tensioning tendons, which are normally single rods or wires. Production normally takes place on a carousel with the frame and moulds moving from one workstation to the next before being held in a curing chamber, where the temperature of the concrete is strictly controlled. When the concrete has reached the required strength the tendons are released from the frames and the load in the tendons maintained by the bond with the concrete. The sleepers are inspected, tested and placed into storage. Casting can be continuous through each 24 hours. A variation of this system is the instant de-mould system where the sleepers are removed from the moulds very soon after casting onto a pallet but where they remain in the stressing frame, allowing the early reuse of the moulds.

4.2.3 Single mould system

Sleepers are produced in moulds one sleeper long with up to four sleepers side by side, which are strong enough for the pre-stressing tendons that are normally single rods or wires, to be anchored on to the mould at each end. The moulds travel between workstations round a carousel and into a curing chamber where the concrete temperature is strictly controlled. When the concrete has reached the required strength the tendons are released from the end of the mould and the load in the tendons maintained by either the bond of the tendon with the concrete or mechanical anchorages at he end of the tendons. The sleepers are inspected, tested and placed into storage.

A variation of this system, the instant de-mould system allows the early reuse of the moulds. A stressing frame independent of the mould is used so that the sleepers may be removed from their moulds onto a pallet soon after casting but remain in the stressing frame. Casting can be continuous through each 24 hours.

4.3 Post-tensioned systems

There are two man categories of production systems for post-tensioned sleepers

- Instant demould
  (Type a in appendix 3)
- Late demould
  (Type f in appendix 3)

Production systems for post-tensioned sleepers have generally all been instant de-mould systems. The sleepers are produced in single or double moulds with internal ducts formed along their length. The moulds travel between workstations on a carousel. Soon after the concrete has been placed and compacted in the moulds the sleepers are removed from the mould onto a pallet and the moulds are made available for reuse. The concrete is cured until it has reached the required strength. Special tendons, normally single wires, are placed in the preformed ducts and are stressed to the required load by tightening nuts on their threaded ends which also maintain the load in the tendons. A cement grout is injected into the ducts to provide protection to the tendons and some bonding of the tendons with the sleeper. Casting can be continuous through each 24 hours.

A variation of this system uses an “egg laying” machine, which travels, casts and places sleepers along a casting area.

In the last few years late de-mould systems have been developed using the carousel method for production but with the demoulding process taking place after the concrete has hardened. The main reason for this development is to preserve geometric accuracy and produce a smoother surface finish.

A recent development in Italy is to produce sleepers with unbonded tendons in a protective sheath which allows them to be in place when the sleeper is cast and avoids the need for subsequent grouting.

4.4 Reinforced concrete sleepers

4.4.1 Twin-block sleepers

There are two basic production methods for twin-block sleepers:

- Instant demould
  (Type g in appendix 3)
- Late demould
  (Type h in appendix 3)

Twin block sleepers have generally been cast using a very dry concrete in a static machine that has a fixed mould into which the reinforcement, steel connecting bar and other components are placed. Immediately after the concrete has been placed and compacted the sleeper is removed from the mould and placed onto a pallet for removal to a curing chamber. When the concrete has reached sufficient strength it is removed for handling, inspection, testing and placing into storage. Alternatively an egg-laying machine can be used which casts and places sleepers along a casting area where they remain until they have reached sufficient strength to handle and remove. Production can be continuous throughout each 24 hours.

Carousel methods of production are also now in use as are late demould systems where demoulding of the sleeper takes place after the concrete has hardened.

4.4.2 Single block sleepers

These sleepers can be produced by the same methods as twin block sleepers.

4.5 Turnout sleepers

4.5.1 General

Production of turnout sleepers, or bearers as they are often called, is complicated by the large variety in the types of sleeper. The rail on the sleeper can be fixed in any position along the length of the sleeper and can be at varying angles to the sleeper. The overall length of the sleeper is another variable. Each sleeper in a layout is therefore likely to be unique. If inclined rails are required the inclination is usually achieved with the use of inclined plates between the sleeper and the rail. There have been solutions where the inclined rail seat is part of the cast sleeper but this method is not widely used.

The huge number of variations of the positioning of the cast in component of the rail fastening system requires separate mould plates for each different sleeper type to hold the component in place during casting. However a variation of this system is to cast the sleeper without the rail fastening component thereby reducing the variables to length only. After the sleepers are removed from the moulds, holes are drilled and the rail-fastening components are glued into the sleeper. This allows a simplified production line for the casting of the sleepers and for a stock of sleepers to be held waiting drilling and gluing. Lead times from order to delivery can therefore be significantly reduced.

Generally sleepers are no longer than 5.5m. In some countries sleepers are manufactured and later connected end to end with steel connectors that can transmit shear forces but not bending moments. In other countries sleepers up to 8.5m long are used.

4.5.2 Long line systems

The sleepers are normally cast on a continuous long line bed from 20 to 150m long with moulds for a single or double line of sleepers. High-grade steel tendons, normally stranded wire, with or with out indents, are anchored at jackheads at each end of the line. Secondary steel reinforcement is placed as required around the tendons.

Concrete is placed and compacted into the mould and the addition of heat can be introduced to accelerate the rate of gain of concrete strength. When the concrete has reached the required strength the load in the tendons can be released from the anchors and the load is maintained in the tendons by the bond with the concrete. The tendons are cut at the end of each sleeper and the sleeper is removed from the mould for inspection, testing and transfer into storage.

4.5.3 Short line systems

Normally up to 4 sleepers are cast side in a mould long enough to accommodate up to 20 m of product which is in a steel-pre-stressing frame. This frame anchors the pre-tensioning tendons, which are normally single rods or wires. Production normally takes place on a carousel with the frame and moulds moving from one workstation to the next before being held in a curing chamber, where the temperature of the concrete is strictly controlled. When the concrete has reached the required strength the tendons are released from the frames and the load in the tendons maintained by the bond with the concrete. The sleepers are inspected, tested and placed into storage. Casting can be continuous through each 24 hours.

A recent development in Italy is to produce post-tensioned sleepers with unbonded tendons in a protective sheath which allows them to be in place when the sleeper is cast and avoids the need for subsequent grouting.

4.5.4 Single mould system

Sleepers are produced in either single or double moulds, which are strong enough for the pre-stressing tendons that are normally single rods or wires, to be anchored on to the mould at each end The moulds travel between workstations round a carousel and into a curing chamber where the concrete temperature is strictly controlled. When the concrete has reached the required strength the tendons are released from the end of the mould and the load in the tendons maintained by either the bond of the tendon with the concrete or mechanical anchorages at the end of the tendons. The sleepers are inspected, tested and placed into storage.

5 Design of precast concrete track systems

5.1 General

The design and performance of precast concrete track systems has to conform to both technical and legal requirements. Normally the design life of a sleeper is greater than 40 years and the manufacturer gives a minimum warranty period to cover materials and workmanship of from 5 to 10 years.

In most countries specifications and standards have been developed which detail the design criteria and test methods of track components. Some of these documents are listed in 5.3 below.

The main requirement of precast concrete track systems is to transmit vertical, lateral and longitudinal, static and dynamic loads from rolling stock through the rails to the ballast or other support while maintaining the track geometry within permitted tolerances. The static loads are due to rolling stock axle load and the dynamic loads are due to rolling stock design, the maintenance of track and rolling stock, and any irregularities in the alignment and support of the track.

The following basic criteria must be established before determining the wheel load:

- track gauge;
- axle loads;
- vehicle speed;
- sleeper spacing in track;
- rail size and inclination.

The design should also take into account any special durability requirements including, for example, climatic conditions, secondary stresses and the possible water retention in and around rail fastening components.

A flow chart is shown in appendix 2 outlining the responsibilities of the purchaser and supplier through from initial contract documents to manufacture.

5.2 Design wheel loads and bending moments

The design wheel load at the sleeper rail seat is determined by consideration of

- the track structure in sharing applied axle loads between sleepers, to determine the static wheel load on each sleeper;
- the factors by which the static and dynamic wheel load should be increased to take into account geometric irregularities in track, the vehicle speeds, and ballast support conditions;
- vehicle characteristics including wheel tread and bearing defects;
- impact attenuation of fastening system.

When these factors have been studied and evaluated the rail seat design load can be established and the magnitude of the bending moments at the rail seat and at the centre (for monoblock sleepers) can be calculated. These bending moments are then used to design the sleeper.

5.2.1 Design of sleeper

Three separate loading cases are normally considered when designing the sleeper,

- There should be no cracks in the sleeper when subjected to the design wheel load.
- Occasionally, sleepers will be subjected to exceptional wheel loads. In these cases cracks should not exceed a small defined width after removal of a load which is a

specified factor greater then the design wheel load. This is to ensure the sleepers remain serviceable even when subjected to these exceptional loads.

- Failure does not occur if the sleeper is subjected to high accidental impact loads. This “factor of safety” will be specified.

Other considerations to be taken into account when designing and detailing the sleeper are:

- Overall size taking into account handling of the sleeper at all stages, the minimum weight requirements for high-speed lines and the maximum allowable pressure between the sleeper and the ballast.
- Minimum concrete cover to steel for maximum durability
- Positioning of the fastening system relative to pre-stressing and reinforcing steel to ensure adequate electrical resistance from one rail to the other.
- Climatic conditions – extremes of temperature

A similar approach will be required for other pre-cast concrete track systems.

5.3.1 Design verification

Calculation of the design capacity of a sleeper is useful when determining the dimensions and reinforcement required. However the design of the sleeper will normally be verified by both static and dynamic load testing in addition to dimensional checking. Loads are applied to the sleeper in a specially designed test rig to verify that,

- No cracking occurs during both static and dynamic application of the design wheel load.
- Cracking is within the specified limits during dynamic loading, when the wheel load is exceeded by the specified factor to take into account exceptional impact wheel loads.
- Failure does not occur when subjected to dynamic loading before the design wheel load is exceeded by the amount specified for high accidental impact loads.

5.3 Examples of standards, and specifications used for the design, approval and acceptance of precast concrete track systems

In Europe documentation is available such as:

- Decision de la commission, 30 May 2002, deals with interoperability of high-speed sub-system “Infrastructure”;
- Directive 2001/16/CE, 19 March 2001, from the European Parliament, deals with interoperability;
- European standard series EN 13230 “Concrete sleepers and bearers”;
- European standard series EN 13481 “Fastening systems”;
- European standards for rail, track work acceptance, etc.;
- European Standard EN13230-1 Annex E, Figure E.1, and UIC leaflet 713R.

UIC research department “European Railway Research Institute” is a major contributor for providing technical issues in the field of track components. Reference documents of ERRI are:

- UIC D170 RP 4 report, 1991, which is a guideline for the design calculation of concrete sleepers;
- UIC leaflet 713R, which is a guideline for the design calculation of monoblock concrete sleepers.

In the USA, American Railway Engineering and Maintenance-of-way Association (AREMA) provides guidelines and technical information for the design of concrete sleepers. This is included in the document *AREMA Manual for Railway Engineering* – Chapter 30.

In Japan there is the Japanese Industrial Standard JIS E 1201.

6 Durability of precast concrete components

6.1 General

Concrete sleepers have proved to be the most durable of all sleepers for today's railways. Indeed it is generally accepted that concrete sleepers can have a life in excess of 50 years. At the FAST track at Pueblo, Colorado, in the USA sleepers are still going strong after approximately 3,000 million tonnes of traffic consisting of 110 tonne freight wagons! There are many factors that can affect the durability of a concrete sleeper. Care and judgement have to be exercised, from initial selection of materials, through production and curing techniques, to the handling, installation and maintenance to ensure that the durability is not compromised.

The choice of fastening system is particularly important so that any part of the fastening embedded in the concrete, which cannot easily be replaced, does not reduce the life of the sleeper.

Codes and specifications usually detail special precautions that must be taken: with the selection of materials, during the production process and post production.

6.2 Selection of materials

Alkali-silica reaction (ASR) is a chemical reaction which takes place in aggregate particles between the alkalis from cement paste and reactive silica that may be present in the aggregate. Water is absorbed and alkali-silica gel is formed. The reaction material expands and produces pressure. If the pressure exceeds the tensile capacity of the aggregates, cracks will propagate across the aggregates.

The formation of ASR requires reactive aggregates, alkalis and the presence of water. Selecting non-reactive aggregates or ensuring that the alkali in the cement paste does not exceed specified levels and that dense concrete with low water permeability will avoid this.

Delayed ettringite formation (DEF) accompanied by expansion, results from the reformation of primary ettringite which had decomposed, or failed to form, during the exposure to high temperatures at hardening (steam curing etc. or excessive heat of hydration). The DEF requires the presence of sulphate ions, starting conditions (high temperature of curing, lowering of pH) and water. DEF can be avoided by limiting the temperature of the concrete during curing and using a dense concrete with low water permeability.

In some concrete structures exposed to a sulphate attack, thaumasite $CaSO_4.CaSiO_3.CaCO_3.15H_2O$ in addition to ettringite also has been identified as a phase associated with expansion and with transformation of hardened concrete into a pulpy mass, since a significant part of C-S-H can be destroyed. There are also indications that formation of this phase is favoured at low temperatures, below 5°C.

Alkali Carbonate Reaction (ACR) The only form of ACR known to be harmful to concrete is the "dedolomitization" reaction which may take place between argillaceous (clay-rich) dolomitic limestone aggregate particles and the high pH of the pore fluids in cement paste. During dedolomitization, dolomite and lime are replaced by brucite and calcite. This reaction leads to a loss of bond between aggregate particles and cement paste.

Abrasion of the soffit of the sleeper or abrasion at the rail seat must of course be limited to acceptable levels. High performance concrete provides abrasion resistance as high as best granite. Tests should be made on the aggregates to check that they have a high resistance to abrasion.

Other useful tests to achieve high durability include water absorption tests and freeze thaw tests on the hardened concrete.

The maximum size of aggregate should be carefully selected. The shrinkage of cement paste is a consequence of the hydration of cement. Hardened cement paste shrinks around the big aggregate particles and microcracks arise. There is also a lesser chance of defects in concrete using smaller size aggregates.

The use of non ferrous embedded items has to be carefully considered to avoid longitudinal tensile cracks and the use of secondary reinforcement may be considered necessary.

6.3 Production process

Methods must be adopted to ensure the adequate compaction of the concrete, the accurate placing of pre-stressing and reinforcing steel, and in the case of pre-stressed sleepers, the controlled introduction of the pre-stress into the hardened concrete. The formation of micro cracks, invisible to the naked eye, must be avoided during the curing of the concrete. The temperature of the concrete must be kept within specified limits at all times from the initial mixing of the concrete right through to the time when it has achieved a high strength. This is to keep any thermal volume change and the resulting strains within limits, which the increasing strength of the concrete can accommodate. Up to the time when the concrete has achieved its initial set there should be no additional heat applied other than the natural heat of hydration. After this time the rate of increase in temperature and the maximum temperature of the concrete, from the hydration of the cement, together with applied heat if used, should be kept within specified limits.

The steel in the sleeper must be detailed so that progressive corrosion cannot take place and affect the life of the sleeper.

The high strength concrete used for sleepers generally has a low water cement ratio and it is very important to prevent drying shrinkage that can affect the durability. Measures should be taken to eliminate this type of shrinkage by preventing the evaporation of water from the surface of the concrete and in hot climates by the use of water curing commencing from the first day of the curing period.

6.4 Post production

Naturally, as with any product, proper rules and procedures have to be followed through out the life of the sleeper to ensure that no physical damage takes place.

Sleepers in track are subjected to high repeated loads in an aggressive environment. Thorough and regular maintenance of all parts of the permanent way are necessary to ensure that these loads are kept within acceptable limits and that the relative movement of the ballast and sleeper is minimised to avoid abrasion of the sleeper and ensure full support under the rail seats.

7 Rail fastening systems

7.1 Functions of the rail fastening

The rail fastening system comprises all of the components, which connect a rail to a sleeper. The purpose of the rail fastening system is to transmit the forces exerted through the rail on to a sleeper, and to hold the rails to gauge. These forces are primarily those from the action of the vehicle on the rail, although the effects of the environment (e.g. temperature) also have an influence. As well as its primary load-carrying role, the system has important functions from the point of view of installation, maintenance and other operating requirements of the railway. The following points are important performance criteria for a fastening system.

- The system must hold the rails to the correct gauge and inclination.
- The system must transmit the rail forces to the sleeper safely. These include forces, which are vertical, lateral (i.e. sideways, across the track) and longitudinal (i.e. along the length of the rail). All of these forces are present, even in straight track.
- The system may be required to attenuate the shock loads, which are caused by imperfect wheel and rail surfaces and must prevent vibration, impact or abrasion damage to the sleeper.
- The fastening must have sufficient elasticity and fatigue resistance to have a long service life.
- Installation and maintenance should be straightforward, using manual or, where possible, mechanised or automated methods.
- There is a requirement for good electrical insulation where signalling track circuits are used, or where the running rails are used for traction current return on an electrified railway.
- The system must not permit excessive gauge spread.
- The components must be inexpensive and should be easily and inexpensively replaceable.
- The components must be designed so that they do not put expensive constraints on the sleeper design and production method.
- The system should be designed so that vandals cannot easily make the track unsafe.

7.2 Fastening types

Rail fastenings are generally described as

- Direct - the rail is attached directly to the sleeper
- Indirect – the rail is attached to the base plate, which is in turn attached to the sleeper
- Rigid - there is no significant elasticity in the components which hold the rail
- Resilient - the component holding the rail is usually some form of spring

Most of the types of fastening systems used on concrete sleepers use high tensile spring clips to apply a large clamping force to the rail. Electrical insulation and impact attenuation are provided by pads and insulators configured to suit the particular design of clip. The clamping force is applied as the clip is installed; either by tightening a screw ("threaded fastenings") or by inserting the clip into a shoulder, which is shaped to force the clip to deflect as it is driven into place ("non-threaded fastenings"). Most modern fastenings are designed so that the clip is deflected by a pre-set amount, and hence applies the required clamping force when it is properly installed, whether the design is threaded or non-threaded.

Increasingly, rail-fastening systems are “pre-assembled” on concrete sleepers before the sleepers are delivered to the track renewal site. Such systems are more easily handled by mechanised equipment. They also reduce the risk of loose components being lost or delivered to the work site in incorrect quantities.

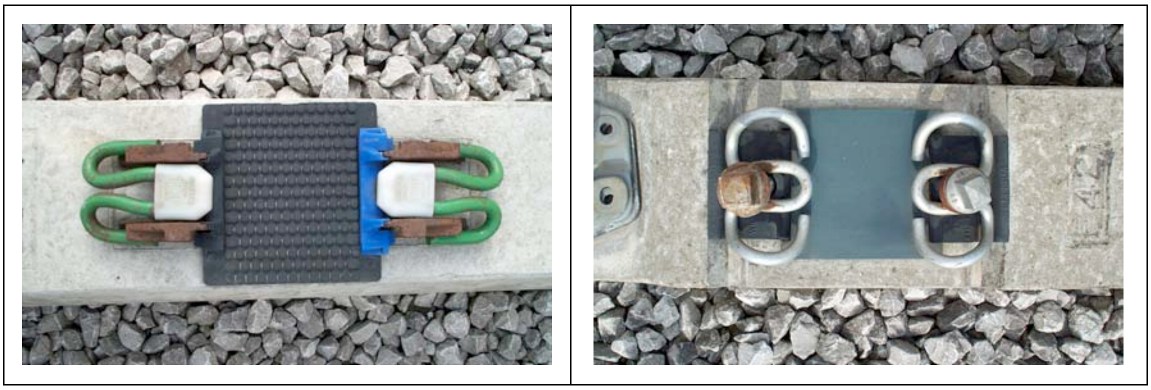

Figure 7-1: Examples of direct pre-assembled fastenings

7.3 Fastening design criteria

A direct resilient fastening has four main features, which are all present in one form or another in the main systems on the market. These features are the clip or spring to hold the rail on the sleeper, the anchor or shoulder that holds the clip, an insulator, and a rail pad between the rail and the sleeper.

7.3.1 Rail clamping force

Clamping forces vary, depending on the fastening system and customer requirement. However, most systems offer a clamping force per clip within the range 7.5 to 12.5 kN with deflections of the clip toe between 10 and 15 mm. It is important for the spring to have a large deflection on installation, so that the clamping force is not significantly affected by variations in the thickness of the pads, insulators and rail (due to manufacturing tolerances or wear in service). The rail clamping force requirement comes from the rail size, vehicle weight and speed, the nature of the track, the radii of curves, temperature range and so on. Current European standards set the minimum longitudinal creep resistance (resistance to pushing the rail through the fastening system) of 7kN for most main line tracks and 9kN for high speed and heavy freight lines. This implies a nominal clamping force per clip of at least 8.5kN for mixed traffic lines and 10kN for the more severe applications.

7.3.2 Cast-in anchor / shoulder

The anchorage of the fastening system in the sleeper has an important role in joining the resilient clip or spring part of the assembly to the less resilient sleeper. It must be capable of withstanding impact loads and vibration transmitted to the sleeper without breaking the sleeper, or coming loose.

Anchorages for threaded fastenings are usually made of nylon or composite materials although polypropylene and HDPE have been used in the past, for light duty applications. Care must be exercised to expel any water during assembly of the fastening to prevent damage in freezing weather. Shoulders for non-threaded fastenings are usually made from ductile cast iron e.g. spheroidal graphite (SG) iron. The shape of the part of the shoulder embedded in concrete has been developed over a number of years to ensure that it reaches down into the pre-stressed area of the sleeper and can transmit lateral and torsional forces safely. The European standard requires that each element of the fastening cast into the sleeper should be able to withstand a 60kN pullout force without damage to the sleeper.

7.3.3 Insulator

Clearly, the insulator is an important component where electrical insulation is required, but in many fastening designs it has an important role to play by stopping wear of other components. It can act as a sacrificial wear element i.e. a part which can be replaced easily, and which wears out itself rather than allowing wear of the rail or shoulder. The insulator material must be resistant to wear, to degradation by ultra violet light and to attack from chemicals used on the track. Most insulators are made from engineering grades of nylon, e.g. glass reinforced nylon (GRN) or high viscosity nylon (HVN). The insulation requirements of the track depend on the nature of the signalling and electrical systems used. The insulation is measured by assembling short lengths of rail at either end of a single sleeper and then measuring the electrical resistance from rail to rail in wet conditions. In the UK Network Rail has set a requirement for a minimum resistance of 10kN in this test.

7.3.4 Rail pads

The main purpose of the rail pad is to spread the load from the rail to the sleeper. The rail pad also has an important role to play in attenuating impact loads from bad joints, track irregularities and faults in rolling stock. The pads must stay in place and not work out in use and, like the insulator, must not degrade in normal use. The use of soft elastic pads provide greatest attenuation of impact loads.

Pads are typically made of rubber, around 10mm thick, or of a plastic such as EVA between 5mm and 10mm thick. The pad stiffness is typically in the range 40 to 450 kN/mm (i.e. it takes between 40 and 450 kN tonnes of force to compress a pad by 1mm), although 5mm plastic pads may have stiffness as high as 600 kN/mm. Plastic pads with a stiffness in range 350 to 525 kN/mm are used in USA in the Northeast corridor and heavy freight routes. On heavy freight lines the elastic behaviour of the pad is of less significance than for high-speed passenger lines. The use of pads of very low stiffness is generally not recommended in curves, as it can cause premature wear of insulators and can exacerbate noise problems. As a general rule, pads with a very low stiffness are not suitable for use in curves sharper than about 400m radius.

7.4 Assembly and maintenance

Normal methods of re-railing may involve the installation and removal of fastenings more than once, for installation of the running rail, de-stressing and so on. It is important, therefore, for the system to be capable of assembly and removal by a mechanised process and the clips must retain the toe-load. It is also an advantage if fastenings are used which remain captive on the sleeper, even when the rail is released.

Any maintenance that may be required in service should preferably be detected by visual examination. Displaced insulators and a new clips or springs must be capable of being inserted by the trackman using hand tools.

7.5 Testing and product acceptance

The testing of fastenings and the performance requirements are specified for example in European Standard EN13146 and EN13481 and the American AREMA Manual for Railway Engineering, chapter 80.

Figure 7-2: Track in Germany with Vossloh rail fastenings (2002)

Figure 7-3: Track in Australia with Pandrol rail fastenings

8 Environmental considerations

8.1 Noise

The movement of the rolling stock and the interaction between the wheel and rail combined with any undulations in the rail or wheel profile produce vibrations over a wide range of frequencies. These vibrations propagate both upwards into the rolling stock and downwards into the track. The higher frequency vibrations, where the head and web of the rail and the rim and disc of the wheel are excited into vibration, can be transmitted into the atmosphere as audible noise.

Concrete sleepers on ballasted track are only passive elements in the track structure and do not influence the origin of the noise. Noise levels are generally a few dB's greater for non-ballasted track. Noise can be of concern to passengers in a train but generally speaking the modern design of rolling stock reduces the noise within railway compartments to well within acceptable limits. It can also be of concern to those who live or work near the track.

Rail corrugations or wheel defects can be a cause of noise. Measures to mitigate the noise levels therefore include rail grinding where there are rail corrugations and the elimination of wheel defects. Other methods include the use of dampeners fixed to the web of the rail or between the rail and the sleeper. In particularly sensitive areas noise barriers as close to the track as possible and high enough can confine excessive noise. There are many such proprietary barriers available.

8.2 Vibration

Vibrations transmitted down into the track can be transmitted to the foundations of nearby buildings. If there are potential problems and if it is not possible to mitigate the effects in the design of the building's foundation, some possible means of improvement include the use of softer rail pads, resilient base plates, or the use of soft pads under the sleeper. Ballast mats have been used under the ballast for new or completely renewed track. Rubber boots or shoes are often used around the sleepers used in non-ballasted track.

8.3 Recycling

Recycling of materials has assumed a very great importance these days and fortunately concrete sleepers can quite easily be recycled. Concrete sleepers have been in use for many years and some are now being replaced when complete track is renewed, in major track alignments or where new rail fastening systems are adopted. Many of the uplifted sleepers may be cascaded down into secondary track and used for many more years. If that is not possible it is now commonplace to crush the sleepers, extracting the steel reinforcement and the cast-in part of the rail fastening with magnets. The steel and castings can be recycled and the crushed concrete used for aggregates in lower grade concrete or, for example, as fill in road construction.

8.4 Contamination of environment

Unlike timber sleepers, no chemical preservatives are required so there is no risk of contamination to groundwater or any harmful effects to personnel working on the track.

The development and wide use of self compacting concrete without the need for vibration provides a much quieter working environment at the place of manufacture and uses less electrical energy.

9 Installation and maintenance of precast concrete track systems

Since the introduction of concrete sleepers and continuously welded rail, plant and equipment has been constantly developed to install the concrete sleepers and to maintain the track in the most economical manner.

The sleepers should be placed with care and precision during their installation.

The completed track must be maintained to keep the ballast correctly distributed beneath the sleepers and free from excessive contamination from the sub ballast and from ballast attrition. The railhead should be kept free from corrugations, wheel burns and distorted joints.

The effectiveness of the plant is paramount but the rate at which these operations are completed is also of vital importance so that the track possession time is kept to a minimum, causing the least disruption to train services.

Methods of installation for new railways can be more straightforward than renewing sleepers on existing track. There are not normally the same restrictions imposed for example, from operational adjacent tracks and overhead electrification. However for renewing existing track the plant has to operate within these restrictions and can involve renewing not only the sleepers but the rail and ballast as well.

Efficient track maintenance requires inspection of the track and recording of measurements. Increasing speeds and loads impose ever-tighter tolerances in track geometry. Therefore recording cars using ultrasonic inspection systems must measure track geometry to a very high degree of accuracy to determine the necessity for track maintenance. Use of video inspections and computer support decision systems can increase the efficiency of this work.

There are now massive machines that have been developed that in one pass can remove the existing rail and sleepers and lay individual sleepers on a prepared base placing the welded rail in the same operation. It is possible that such machines can replace existing track at the rate of 0.5 km/hour.

There are several different maintenance operations necessary. The main one is tamping and lining. This is necessary to improve the horizontal and vertical geometry of the track with the minimum amount of disturbance and minimum use of ballast. Tamping machines lift the track and pack and consolidate the ballast under the sleeper without the machine coming to rest during the cycle. They can operate at over 1.5 km/hour. Another method for achieving the same result is with the use of a Stoneblower. The Stoneblower lifts the track and introduces a measured amount of smaller stone on top of the undisturbed ballast below. This method has the advantage that unlike tamping it does not disturb the existing track ballast, which should improve the intervals between track maintenance and delay the need for re-ballasting. It is however, not so effective when the ballast below the sleepers is new because the introduced smaller stone moves down between the larger pieces of normal ballast. Both types of machine can have an onboard facility to survey the track, and design and implement the revised alignment.

Dynamic Track Stabilisers are used to follow tamping and lining work to induce consolidation of the ballast beneath the sleepers and therefore reduce the time for the ballast to settle to a steady state, following any disturbance.

Ballast Cleaners are necessary to keep the ballast in good condition. The ballast is removed from the track without the need to remove the rails and the excavated material is screened and reusable stone returned to the track. Specially designed high output ballast cleaners can operate at the rate of 2 km/hour.

Rail grinding is also normally used when new track is installed or renewed and at other times if required. Rail mounted equipment utilising rotating grinding stones can work at between 5 and 8 km/hour. It has been shown to have beneficial effects in reducing maintenance costs. It is also used to remove railhead corrugations and to restore the railhead profile.

10 Research and development

10.1 General

The relevance of research and development devoted to durability has already been referred to in chapter 6. The increased knowledge of material properties and its behaviour has helped develop reliable manufacturing and control processes to maximise long-term durability. Development in automation of production processes has increased not only productivity, but also uniformity and quality.

The new European standard EN 13230 and other documents like the UIC Project - Monoblock Concrete sleepers-Design and Optimisation - have moved to a more unified approach to the technical evaluation and testing of the performance of concrete sleepers. The EN requires important parameters such as the design moments, to be specified after consideration of track stiffness and traffic conditions by the relevant railway authority. The trend to heavier axle loads for freight transport and higher speed passenger trains has resulted in demanding mechanical and geometrical requirements being specified and checked in accordance with the new standards. These standards are vital when considering new sleeper designs and developments of improved manufacturing processes.

Research and development is ongoing in most countries and several main trends have been identified as follows:

a) The design and testing procedure considers three stages of loading following studies into the post cracking behaviour of sleepers. There should be no cracking when subjected to the normal design service loads, there should only be minimal cracks with a maximum specified width after being subjected to exceptional loads (around 50% higher than service loads) and there should be a minimum ultimate strength to withstand exceptional accidental impacts. The dynamic testing that has been developed to check these various stages of loading is in good agreement with the real conditions of the sleepers in track.
b) These objectives have been achieved following the research on the behaviour of the anchorage region in all systems, mainly in those using anchorage by bond. Serviceability and durability, after exceptional loading, is controlled, by the specified maximum limit to the width of the remaining crack in the dynamic test. Progress in materials has led to increased concrete strengths and increased bond of the tendons and the concrete.
c) There has been a trend towards tighter tolerances for better track quality, particularly the positioning of the rail and its inclination and the relative twist of adjacent rail seats.
d) New rail fastenings often use more elastic pads, mainly for high-speed trains. Interaction between the rail and the sleeper using these softer fastenings has focused on the attenuation of peak stresses in the concrete sleeper. Continuous monitoring of actual installations is essential for continuous developments. In the USA, where heavy freight generates large lateral forces, the main research has been directed at improving the rail fastening hardware life and the elimination of rail seat attrition.
e) High-speed trains and greater braking forces has led to the use of heavier sleepers with improved bottom frictional surface and end shapes based on theoretical and experimental studies.
f) The use of concrete sleepers for crossings and turnouts has, in the last ten years, become the preferred solution for new lines. Durability and long term geometrical reliability are the main reasons for this trend. There is much development in production systems to cater for the hugely varied geometrical pattern of the positions of the rail fastenings. Manufacturers are progressing standardization but different

fastening systems and non-uniformity on the whole crossing or turnout design philosophy (for example whether or not inclined rails should be used) makes this a difficult task. Continuous improvements in geometrical accuracy and camber control have been achieved based on material knowledge and accumulated experience. These parameters become more critical for longer bearers. Some manufactures produce bearers longer than 3.5m either in one unit or by joining individual units by mechanical couplers. Solutions like this are adopted after thorough experimental work.

g) A UIC working group is currently preparing a report on non-ballasted track.
h) Under-sleeper pads, and their influence on track stiffness, ballast degradation and vibration absorption are becoming more widely utilised.
i) Self-compacting concrete has been used recently in some manufacturing methods following a general trend in the pre-cast industry. Research on this new material to achieve the required high strengths has been extensive.
j) Extensive work has been carried out on the long-term durability of sleepers. There have been no reported new cases of longitudinal cracking arising from expansive reactions in the concrete.
k) Another aspect of durability is the possibility of micro cracking around some rail fastening components cast into the sleeper. This has led to the adoption of different materials being used for the componets or for the introduction of secondary helical reinforcement.

10.2 Specific research projects

The main research and development activities in different countries are:

1 Materials behaviour and durability
   a. Achievement of long-term concrete mechanical properties.
   b. Study of role of autogenously and self desiccation shrinkage.
   c. Study of size of aggregates for optimal performance.
   d. Role of some mineral admixtures.
   e. Effect of non-metallic fibres.
   f. Alkali-aggregate reaction potential.
   g. Application of fracture mechanics to quality control of concrete.
   h. Accelerated test method of aggregate-cement reaction on concrete specimens, correlation with real behaviour of prestressed sleepers.
   i. Rail seat wear in heavy haul railways.

2 Crack control
   j. Investigation into likelihood of longitudinal splitting around vertical holes in sleepers.
   k. Stress and chemical study on longitudinal cracking. Incorporation of the influence of manufacturing and curing process.

3 Rail fastenings
   a. Development of pre-assembled fastenings.
   b. Optimisation and control of the behaviour of sleepers’ fastenings for high-speed track.

4 Track geometry and elasticity.
   a. Tighter tolerances for improved track geometry.
   b. Use of smaller ballast to maintain track geometry.
   c. New sleepers to maximise ballast contact area.
   d. Use of under sleeper pads to minimise ballast wear, for noise control and reduction in ballast thickness.

    e. Low profile sleepers.
5 Optimisation of the entire track behaviour.
    a. Development of trains/track theoretical model including rail corrugations, wheel flats, validated by means of results from in field measurements. The entire behaviour is optimised for each track component.
6 Cost considerations
    a. Production of whole life cycle cost model comparing concrete with steel sleepers (see appendix 4 for parameters to be considered).
    b. Introduction of self compacting concrete.
7 Design and supply
    a. Track systems for greater axle loads and speeds

11 Conclusion

The worldwide use of precast concrete is illustrated in Appendix 3 and demonstrates that there is worldwide agreement that precast concrete provides the best solution for both high speed and heavy haul track.

Figure 11-1: High speed and heavy haul track, DB AG/Jazbec (2004)

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Appendix 1: Typical quality plan

Operation or Activity	Requirement	Specification	Inspection equipment	Dept.*	Frequency	Required documents
Receive order/ call off - contract review		Manufacturer's procedures	N/A	Sales	Every order	
Production plan		Purchaser's spec.	N/A	PD	Every order	
Order materials		Approved Suppliers	N/A	PD	Every order	
Incoming material	**Check all delivery tickets**					
Strand	Inspection for damage	Manufacturer's procedures	Visual examination	PD/QC	Each delivery	Certificate of Conformity
Aggregate	Sieve analysis	BS EN 12620 & PD 6682	Sieve's	QC	Once/week	QA form completed
	Taber indexing (sand)	Purchaser's spec.	Out-sourced	QC	Bi-annual	Certificate of test
	Chloride ion	BS 8110 <0.1%	Out-sourced	QC	Annual	Certificate of test
	Acid soluble	BS 8110 <4%	Out-sourced	QC	Annual	Certificate of test
	Petrographical		Out-sourced	QC	Bi-annual	Report stating ASR issues
	Organic content (sand)		Out-sourced	QC	Annual	Certificate of test
Cement	Check for emissions	BS EN 197	Visual examination	PD	Every delivery	Certificate of Conformity
PFA	Check for emissions	BS EN 450	Visual examination	PD	Every delivery	Certificate of Conformity
Water	Chloride ion		Out-sourced	QC	Annual	Certificate of test
Admixture		BS EN 934-2	Proctor	QC	Each delivery	
Cast in components			Visual examination	PD	Each delivery	Certificate of conformity
Compression test for transfer	Transfer result >40.0 Nmm2	Manufacturer's procedures	Compression machine	PD	Each line	Print out!
Curing	Rate of gain <10 °C/0.5hr & <15 °C/hr max temp < 50°C	Manufacturer's procedures & Purchaser's spec.	Chessell recorder	QC	Every cast	QA form completed
Paint on batch number	Batch identification	Manufacturer's procedures	None	PD	Every unit	QA form completed
Saw off moulds		Manufacturer's procedures	None	PD	Every mould	
Demould		Manufacturer's procedures	None	PD	Every mould	
Remove for storage/delivery	Visual inspection	Manufacturer's procedures	Visual examination	PD	Every unit	QA form completed
Select test & gauge samples	Random	Manufacturer's procedures		QC	Each line	QA form completed
Part gauging	Track	Manufacturer's procedures & purchaser's spec.	Track gauge	QC	5% calculated monthly.	SPC database & QA form
	Seat		Seat gauge	QC	5% calculated monthly.	SPC database & QA form
	Fastening height		Fastening height gauge	QC	5% calculated monthly.	
Damaged or defective moulds	Remove from production	Manufacturer's procedures	None	PD/QC	Every mould	QA Form
Cleaning moulds		Manufacturer's procedures	None	PD	Every mould	
Placing of strand		Manufacturer's procedures	None	PD	Every line	Record in sleeper database
Tension strand	68 Kn of prestress per strand.	Manufacturer's procedures	Flags on Jack Head	PD	Every line	
	Calibration of stressing equipment	Manufacturer's procedures	Pressure Transducer and load cells.	QC/PD	Every line - each month	Calibration system

Operation or Activity	Requirement	Specification	Inspection equipment	Dept.*	Frequency	Required documents
Mix design	Setting time (mix)	Manufacturer's procedures	Proctor	QC	Monthly/new design	Proctor setting report
	Acid soluble	BS 8110 <4%	Calculation	QC	Monthly/new design	Mix design form
	Maximum alkali	BRE Digest 330 <3.5 Na2Oeq/m3	Calculation	QC	Monthly/new design	Mix design form
	Total chloride	BS 8110 <0.1%	Calculation	QC	Monthly/new design	Mix design form
Precast inspection.		Manufacturer's procedures	None	QC	Every line	Preline inspection form
Casting		Manufacturer's procedures	None	PD		
Make transfer & 28-day cubes	28 day >60.0 N/mm2	BS EN 206	100 * 100 mm Cube moulds	PD/QC	Every line	Cube compliance database
Moisture content (sand)	Ensure correct water content.	Manufacturer's procedures	Weigh scales/ microwave	PD	Start of each line	Mix printouts - W/C ratios
Flow tests	Check workability	Manufacturer's procedures	Flow apparatus	QC	Each line	Concrete analysis report.
End plate removal.		Manufacturer's procedures	None	PD	Each mould	
Positive bend test		Manufacturer's procedures & Purchaser's spec.	Test house - sleeper test rig (load Span - 560mm for LUL & 600mm for network rail)	QC	Each line	QA form & sleeper database
Full Gauge	Track	Manufacturer's procedures & purchaser's spec.	Track gauge	QC	2.5% calculated monthly	SPC database & QA form
	Seat		Seat gauge	QC	2.5% calculated monthly	SPC database & QA form
	Fastening height		Fastening height gauge	QC	2.5% calculated monthly	QA form & sleeper database
	Length		Tape measure	QC	2.5% calculated monthly	QA form & sleeper database
	Centriod of prestress		Tape measure	QC	2.5% calculated monthly.	QA form & sleeper database
	Twist		Twist gauge	QC	2.5% calculated monthly	QA form & sleeper database
	Flatness of rail seats		Convex & concave gauge	QC	2.5% calculated monthly	QA form & sleeper database
	Inclination of rail seats		Inclination gauge	QC	2.5% calculated monthly	SPC database & QA form
	Depth at rail seat		Depth gauge	QC	2.5% calculated monthly	QA form & sleeper database
Stacking		Manufacturer's procedures	None	PD	Every unit	
Electrical resistance testing	5 >10k-ohms	BS EN 13146 - 5	Electrical test rig	QC	Every SLP type - annual	Electricial resistance report
Marking	Identification	Manufacturer's procedures & purchaser's spec.	None	PD	Each sleeper	Sleeper database
Loading & delivery		Manufacturer's procedures	None	PD	Each load	SAP

* PD = Production; QC = Quality Control

RED = Major QA activity & hold points for feedback

Appendix 2: Flow chart: responsibilities of purchaser and supplier prior to commencement of mass production

Railway authority purchaser | **Concrete sleeper supplier**

Provides contract document and all design data including:

- Design bending moments
- Safety impact coefficients
- Critical dimensions of sleeper and full profile definition
- Maximum/minimum weight
- Preferred rail fastening system

Provides for approval:

- Detailed drawing
- Description of manufacturing process
- Details and source of materials to be used

Approves detailed drawing of sleeper

Manufactures sleepers for design approval tests
Provides production file including:

- Specification and source of cement, aggregates, admixtures, prestressing steel or tie bars, secondary steel reinforcement, rail fastening system
- Prestressing force for prestressed sleepers
- Method of production including concrete vibration and concrete curing
- Method of storage and transportation
- Method of testing

Performs all design approval tests on materials and finished sleeper

Provides design approval test report
Provides quality plan including

- Details of organisation and responsibilities for manufacture, quality control, procurement of materials, manufacture, customer liaison,

Provides approval for production to commence

Manufactures sleepers in accordance with quality plan and production file

Appendix 3: Worldwide survey on use of precast concrete track systems

All numbers are approximate.

Country	Total sleepers in track	Concrete sleepers					Turnout sleepers per year	Slab track		Other sleepers	
		sleepers in track	sleepers per year	produc-tion type ***	life expectancy	warranty		total	per year	steel per year	wood per year
	1000's	1000's	1000's		years	years	lin m	km	km	1000's	1000
Algeria				g							
Argentina		70	60	e,g,c		10					
Australia	600'000	20		e	50		yes	>1'000		150	200
	3 standard gauges 40 tonne axle loads heavy haul lins						trialing shallow depth sleeper for spot replacement of timber				
Austria	9'000		200					125	10	70	100
Belgium	9'912	5'752	400	e	40	6	1'000	30	0	2	20
Brazil	50'000	6'000	0 to 500	e,g,c	60	10	500	10	0 to 0.3	0 to 60	300
Chile	5'300	350	0 to 200	a	60	10					
China	115'000		3'000								
Colombia	5'080	2'745									
Czech Rep.	17'000	15'000	250	d	30	5	40'000	nil			3
Denmark			150	e			50'000				
France	60'000	40'000	800	b,c,d,g	50	5	50'000	200	0 to 10	0	400
Germany	70'000	40’200	1'400	a, c	30	5	280'000	1'000	100	100	100
	new 30t sleeper										
Greece	6'150	2'150	30	e	60	5		7	0	5	3
	1.7m steel and 2.3m timber to be replaced by concrete										
Hungary	20'388	13'513		d			30'000				
	spiral reinforcement round cast in rail fastening										
India	163'500	72'688	4'640	c,d,e							
	8'000'000 steel and 1'000'000 timber being replaced by concrete										
Italy	40'000	38'000	2'000	a, c, f	50	10	125'000	100	10		
Japan	34'000		400					2'500			
	Shinkansen lines 300 km/hr 2'500 km (10% total)				12m long ladder track recent development						
Malaysia	3'000	2'000	*	e	50	5	imported				turnouts
	* no fixed maintenance programme										only

Country	Total sleepers in track	Concrete sleepers					Turnout sleepers per year	Slab track		Other sleepers	
		sleepers in track	**sleepers per year**	**produc-tion type *****	**life expectancy**	**warranty**		**total**	**per year**	**steel per year**	**wood per year**
	1000's	1000's	1000's		years	years	lin m	km	km	1000's	1000
Morrocco	5'000										
		new concrete sleepers relaying programme commenced									
Netherlands	8'500	'	400	e	30	10	90'000	103	100		
	twin block sleepers no longer used										
Norway	3'000	2'000	60	e	60	5		negligible			
	10000 timber to be replaced by concrete										
Romania	16'000	12'000	12	e	25	5	12'000				
							wood				
Russia	150'000	110'000	3'500								
S. Africa	43'000	21'570	305	c,e	40	5	66'800	0	0	0	0
Spain	30'000	24'000	1'200	a,b,c,e, f, g	30	5	40'000	24	0	0	30
Sweden	19'500	13'000	400	e	50	5	25'000				8
	increased axle loads and speeds anticipated										
Switzerland	17'000	4'500	150	e	40/60		50'000	70			
	slab track only in tunnel projects										
Taiwan	4'000	3'800	120	b,e,h	30	5	18'000	320	32	0	12
USA	600'000	25'000	1'000	e	30	10	300'000	20	2	10	13'000
	trials with plastic sleepers rail seat abrasion on cuves on heavy haul lines now overcome										
UK	45'000	30'000	500	e	50		100'000	5	0.5	400	100
	30 tonne axle loads now introduced twin block sleepers on Channel tunnel rail link										
Venezuela	1'225										

*** Production type:

a	mono block	instant demould	post-tensioned	
b	mono block	instant demould	pretensioned	
c	mono block	late demould	pretensioned	1 mould long
d	mono block	late demould	pretensined	several moulds long
e	mono block	late demould	pretensioned	long line
f	mono block	late demould	post-tensioned	
g	twin block	instant demould		
h	twin block	late demould		

Appendix 4: Parameters to be considered when evaluating whole life cycle costs

When considering the life cycle cost of precast concrete sleepered track, the following parameters should all be evaluated:

Installation costs

- Sleeper ex works
- Transportation sleepers to track installation
- Installation plant and labour
- Track possession time (if renewal)
- Length of installation
- Temporary slow orders immediately following installation
- Life of sleeper
- Life of rail
- Life of ballast

Maintenance costs

Frequency and method taking into account required ride quality

- Planned inspections
- Track alignment – tamping or stoneblowing
- Rail grinding
- Ballast cleaning
- Ballast renewal
- Rail renewal
- Rail fastening renewal
- Un-planned call out costs
- Consequential costs of call outs

Operating conditions

- Axle loads
- Speeds
- Annual gross tonnage
- Fuel cost

The evaluation should consider a wide range of discount rates and discount periods.

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