CONCRETE ROADS

An Overview of Design, Specification and Construction Issues

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Paper first presented at a joint meeting of The Civil Division, Institution of Engineers of Ireland and The Irish Concrete Society on Monday 4th February 1991.

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ABSTRACT

This Paper reviews aspects of the design, specification and construction of concrete roads.

The contribution of concrete to road construction in a number of countries is outlined in the context of the developing position regarding concrete roads in Ireland.

Design philosophy for concrete pavements is discussed together with aspects of the various types of pavements in use throughout Europe. Specification requirements, particularly in relation to materials, skidding resistance and joints, are reviewed and issues deemed relevant to the situation in Ireland are highlighted. The two types of construction technology employed for concrete roads are outlined.

The overall economic and technical benefits of a more open tendering policy for major road projects in Ireland are explored with particular note taken of whole-life cost concepts.

CONTENTS

1. INTRODUCTION

1.1 The strategic importance of a quality road network

Due to the low level of urbanisation in Ireland and our widely dispersed low density population structure, Roads and Road-building have always been significant factors in Irish life. As we enter the last decade of the twentieth century roads are the predominant mode of inland transport in Ireland and a good quality road system is fundamental to the economic well-being of the country. Our roads currently account for 96% of passenger travel and 90% of freight travel within the country. This dependence on the road system is greater than that of most of our partners within the European Economic Community.

With the completion of the Single European Market due in 1992 and the opening of the Channel Tunnel a year later, it is essential to the competitiveness of Irish industry, agriculture and tourism that our transport systems, and particularly our road systems, are competitive and efficient.

There have, in recent decades, been a number of studies of the country's road development needs and serious deficiencies have each time been highlighted. Various road programmes have been developed to improve the situation, the most recent strategic plan being the "Operational Programme, Road Development 1989-1993" (1) which was submitted to the Commission of the European Communities on 30th March 1989 by the Government. This Programme was drawn up within the context of the National Development Plan (2) which has as one of its primary objectives the preparation of the economy for 1992.

The rate at which previous programmes were implemented gave rise to dissatisfaction in some quarters and unease has been expressed recently at the current rate of progress and the stop-start nature of some major developments (3).

However, there is no doubt that in recent years we have seen a major change in the level of activity in new road construction in Ireland.

It was argued in 1986 by the Irish Concrete Society (4) that, with the projected increase in road construction activity, the time was opportune to review design and construction practices to establish their adequacy for future needs and specifically to ensure that in the national context we were achieving value for money in the design and construction of our national road network.

However, current design and construction practices for major road projects, in general, follow traditional lines. In principle, all major road construction projects are let to tender with a single design solution utilising flexible pavement construction, though some choice as regards flexible or rigid roadbase may be allowed. This situation whereby concrete pavements are excluded at the design stage from playing their part in the development of the national road network is somewhat unique in Western Europe and generally in the developed world.

Current practice in Ireland is particularly surprising, given the indigenous nature of the raw materials for concrete road construction and the consequent lower import content associated with the concrete alternative.

1.2 Concrete Roads – a brief historical perspective

It is interesting to note the situation that existed very soon after the foundation of the State in the 1920's when, following appropriate legislation, a period of unprecedented activity in road improvement reached its peak in 1927-28. Herlihy in his Paper (5) to the Institution of Civil Engineers of Ireland in 1951 described in some detail the engineering solutions adopted to improve the road system at that time. It is clear from his chronicle that the first major road improvement projects carried on after the foundation of the State saw concrete play a significant role.

Since that time concrete roads have not been a major issue in Ireland and with few exceptions flexible black-top construction has been the material used for all major road projects.

This lack of interest in concrete, particularly in the last 40 years, is reflected in the fact that, while there have been many Papers presented to the Institution of Civil Engineers of Ireland and the Institution of Engineers of Ireland dealing generally with the development of our road network, only one Paper dealing specifically with concrete roads appears in the index to the Transactions of both Institutions from 1951 to the present – 1991. This Paper by McMahon appeared in the 1966/67 Transactions of the Institution of Civil Engineers of Ireland and dealt with the "The Design of a Continuously Reinforced Concrete Pavement" (6). The Paper dealt with design principles and was not a review of a particular project in Ireland.

It can be postulated that the reason concrete has not played an important role in recent decades in the development of our road network is to a large extent associated with the piecemeal fashion in which our road system has been developed and the stop-start nature of many of the projects undertaken.

Also, some engineers have a negative perception regarding noise levels and riding quality based on experience with roads manually constructed for another era.

Mechanical methods of construction, improved specification parameters and appropriate detailing, particularly as regards joints and surface finish, mean that there is no reason why concrete roads cannot be constructed in Ireland to the highest international standards and take their place alongside alternatives as the current development plans for our road network are implemented.

1.3 Concrete Roads – an international perspective.

Experience abroad throughout this century and particularly in recent decades is quite different to that of Ireland.

In the United States of America, where even by 1925 over 600 million square metres of concrete road pavements were in service, the Interstate Highway Programme has used concrete for over 50% of the network.

In Germany an autobahn system was put in place in the early part of the century. This is one of the most famous purpose built road networks in the world and 90% of the system was constructed in concrete.

In the United Kingdom, commencing in 1969, and with the intention of stimulating competition between alternative forms of construction, Highway Authorities were required by the Government to prepare comparable designs for both rigid and flexible pavements. At the same time an alternative tendering system was introduced whereby contractors were required to submit prices for the construction of both types of pavement. A minor change to this policy was made in the mid 1980's whereby the contractor is permitted to price only one option if he wishes. It has been reported by Mildenhall et alia (7) that in almost all cases, the type of pavement that is chosen is determined by the contractor's lowest tender price. This is in spite of the fact that flexible construction is effectively designed for a 20 year life whereas concrete pavements are designed for a 40 year life. There are signs that whole-life costing may be taken into account in the U.K. in the near future. This issue is referred to later in the Paper. As a result of the Government policy decision of 1969 concrete's share of the market grew significantly in the U.K. from 6% in the 1960's to a peak of 55% in 1980. In the mid 1980's concrete's share was about 40%.

In Belgium all new major roads outside urban areas have concrete pavements and continuously reinforced pavements are the norm. Belgium has a long history of concrete road construction. The oldest concrete roads in Belgium were constructed in the period 1910-1920 (8).

In Austria approximately 50% of the motorways (i.e. about 650km) have been constructed in concrete and excellent performance over 30 years is reported (9).

In Germany where the pioneering work on the autobahn system was carried out in the 1930's concrete continues to play an important part in major road construction and new pavement technology ideas using superplasticised concrete are now being used widely in high early strength heavily loaded urban applications such as bus lanes (10).

Synoptic Tables on current practices in concrete road design and construction throughout Europe have been prepared and presented at recent International Conferences on Concrete Roads. The most up to date Table was presented at the 6th International Symposium on Concrete Roads held in Madrid in October 1990 (11). The Table lists practices in 15 countries in Europe from Finland in the north to Italy in the south and from Portugal in the west to Czechoslovakia in the east. There is no reference to practice in Ireland.

1.4 The case for concrete roads in Ireland

Following on the publication by the Department of the Environment of "Policy and Planning Framework for Roads" (12) in January 1985 the Irish Concrete Society studied the potential suitability of concrete pavements for major new road projects in Ireland. The Society's Report "The Case for Concrete Roads in Ireland" (13) was published in February 1986 and concluded that concrete pavements when compared to alternative flexible pavements were:

- **Twice as durable**
- **Cost competitive**
- **Safer**
- **Similar in riding quality and noise levels**
- **Lower in import content**

The Society's Report was presented to the Department of the Environment and following consultations the Department has confirmed to the Society that a major road project in the Dublin area due to go to tender shortly will be let "as a pilot project" with a concrete pavement option included.

Sharp (14) has noted in relation to "pilot" or "trial" projects that, while they may be seen as appropriate in some countries, "there are no experimental aspects of using large scale concrete roads in normal conditions – the design and construction processes are very well established and practical".

2. DESIGN

2.1 Design Principles

The structural design of road pavements in Ireland has traditionally followed, in general terms, the recommendations contained in the U.K. Department of Transport guidelines on road design. The current U.K. Department of Transport standard for the structural design of new road pavements for motorways and other trunk roads is HD 14/87 "Structural Design of New Road Pavements" (15). This standard has an accompanying Advice Note HA 35/87 (16).

The standard takes account of the most up-to-date information available on road design and, in particular, the research findings of the Transport and Road Research Laboratory reported in Research Report 87 – Thickness Design of Concrete Roads (17). This very interesting background document to the standard notes that the design curves in Road Note 29 (18), which is superseded by the standard, were largely based on observations made on experimental roads prior to 1970 when none had carried more than 10 million standard axles. By 1985 experimental sites being monitored by TRRL had carried considerably in excess of this amount of traffic and consequently broader data was available on which to base new design curves. In fact, research data on 29 types of unreinforced and 42 types of reinforced pavement has enabled performance to be interpreted in terms of the major pavement variables – slab thickness, concrete strength, amount of reinforcement and foundation support. Equations were developed by the researchers relating pavement life to the major pavement variables.

It is interesting to note that good agreement was found between pavement designs derived from the regression models used in RR 87 and those obtained by the AASHTO design method (19) used in the United States.

Research Report 87 is an extremely useful document not only because it provides an in-depth background to the design philosophy incorporated in HD14/87 but also because it includes a listing of valuable references on primary research on concrete road design. The research findings of the Report are simplified for easy use by the designer in the design charts of HD14/87.

There are basically four different types of concrete pavement. Three are defined as 'Rigid' construction. The fourth is defined as 'Rigid Composite' construction.

The three types of 'Rigid' construction have concrete surface slabs which are designated -

(a) Jointed Unreinforced Concrete Pavement (URC)

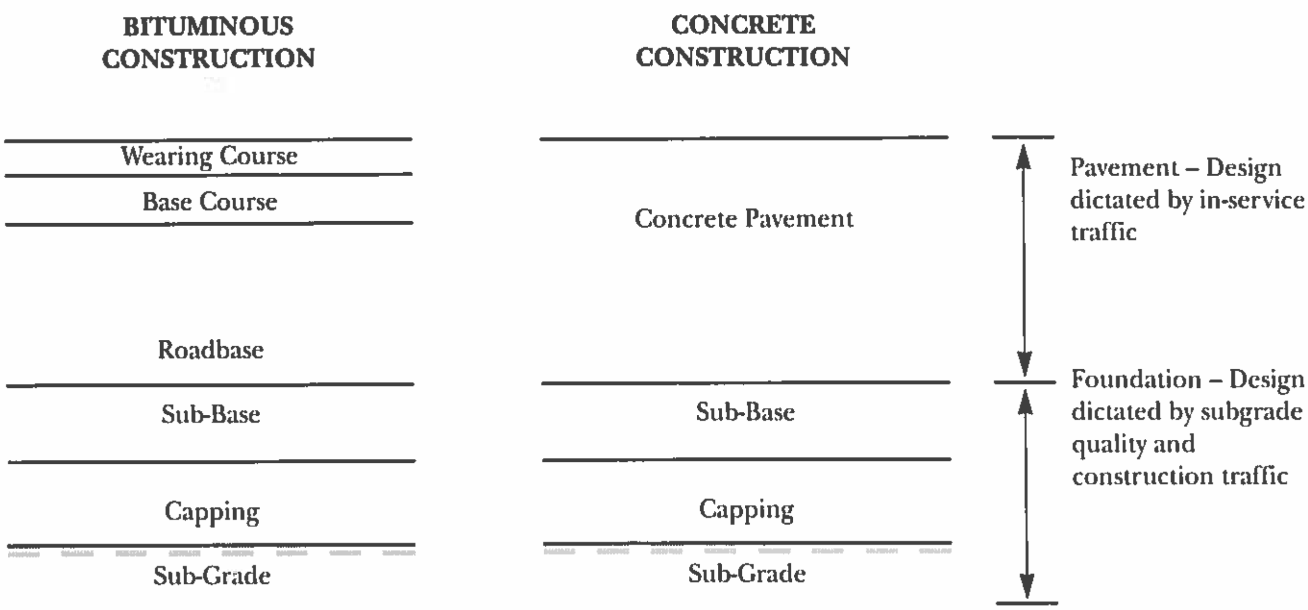
(b) Jointed Reinforced Concrete Pavement (JRC)

(c) Continuously Reinforced Concrete Pavement (CRCP)

The one type of 'Rigid Composite' construction consists of the following -

(a) Continuously Reinforced Concrete Roadbase with Bituminous Surfacing (CRCR).

The basic principle of design adopted in HD14/87 is that the pavement design is dictated by in-service traffic while the foundation design is dictated by the subgrade quality and construction traffic. The terminology used and the general design philosophy adopted are illustrated for both bituminous and concrete construction in Figure 1.



Road Terminology and Design Philosophy (HD14/87)
Figure 1

Designs for Jointed Unreinforced and Jointed Reinforced pavements are based on the analysis of full-scale experimental roads reported by TRRL in RR 87 and on the observed behaviour of trunk roads including motorways.

Designs for Continuously Reinforced Concrete pavements are empirical and have been assessed by comparison with Jointed Reinforced Concrete design. Designs for Continuously Reinforced Concrete Roadbase (CRCR) are based on those for CRCP allowing for the thermal insulation and structural strength of the bituminous surfacing.

All the design charts allow for the improvement in pavement load carrying capacity if the concrete slab extends 1 metre or more beyond the edge of traffic lanes carrying commercial vehicles. When this is not the case a thicker slab is required and guidance is given on the increased pavement thickness.

The standard is clear in requiring that pavement construction above formation should be constant in materials and thickness across the width of the pavement including hardstrips and hard shoulders. This requirement was introduced to deal with maintenance situations where commercial vehicles would be travelling outside the traditional carriageway. This is not the practice in all European countries where thinner pavement layers are sometimes permitted for hard shoulders or material of a lower specification is used. In Ireland, in flexible construction different specification parameters frequently apply to hard shoulders. It is appropriate that this issue is rationalised with respect to both flexible and rigid construction in a manner which does not introduce a bias in favour of one option.

A separation membrane is required in Jointed Unreinforced and Jointed Reinforced construction between the pavement slab and the sub-base to reduce friction and inhibit the formation of cracking in the bays.

2.2 Pavement Life

Design life for concrete pavements is taken as 40 years. At the end of the design life a failure condition is deemed to exist and the pavement is deemed to have reached the end of its initial service life. The rate of cracking will increase rapidly at this point in time. At the end of this useful life the pavement may be strengthened to extend its life.

During the 40 year life it is accepted that some maintenance will be required. This will most likely take the form for Jointed Concrete construction of

- resealing of joints
- some arris or thin bonded repairs
- restoration of texture depth
- some slab replacement

Maintenance of Continuously Reinforced pavements is likely to be associated with punch-outs or spalling and as regards the Continuously Reinforced Roadbase the only maintenance required is likely to be associated with the bituminous surfacing.

'Failure' condition is defined in Advice Note HD 35/87 for the different pavement types as follows -

Jointed Unreinforced Concrete

An individual bay has failed if

(i) A medium crack (>0.5mm with partial loss of aggregate interlock) or a wide crack (>1.3mm with complete loss of aggregate interlock) crosses the bay longitudinally or transversely.

(ii) A medium longitudinal and transverse crack intersect, both cracks starting from an edge and longer than 200mm.

(iii) A wide corner crack of radius >200mm centred on the corner opens.

It is suggested that approximately 30% of bays will have reached one of the failure conditions at the end of a 40 year period carrying the design traffic loading.

Jointed Reinforced Concrete

An individual bay has failed if the length of wide cracking per bay exceeds one lane width. It is suggested that up to 50% of bays may have reached this condition by the end of the design life.

Continuously Reinforced Concrete

As regards Continuously Reinforced Concrete pavements and roadbases it is suggested that strengthening will not be required for 40 years. Sufficient data is not yet available to define failure conditions.

While flexible pavements are also designed for a 40 year life, major maintenance in the form of overlaying and/or partial reconstruction is deemed to be necessary after 20 years. In effect, therefore, this staged construction approach means that the design life is in fact 20 years. At the 20 year point a critical condition is deemed to occur at which point major strengthening is required.

Maintenance, in addition to the major strengthening required at 20 years, will normally take the form of surface dressing or resurfacing at the 10 and 30 year intervals at least.

While concrete pavement designs have been winning contracts in the U.K. and elsewhere on the basis of initial cost only, it would appear that whole life costing, taking into account not only maintenance costs, but also the ever increasing national economic cost of traffic delays is the only rational way forward when comparisons are made between pavement options. This concept has been a factor in road design in some countries, notably Belgium, for many years and the author understands that it is currently receiving serious attention in the U.K.

2.3 Traffic

In the various design charts in HD 14/87 traffic loading is expressed in commercial vehicles/day at the time of opening. A commercial vehicle is defined as a vehicle having a weight over 1.5 tonnes gross vehicle weight.

A 2% traffic growth rate is used and with a required rounding up of pavement thickness to the nearest 10mm a conservative design is deemed to result. The charts have been prepared assuming a year of opening of the year 2000 and allow for the forecast increases in commercial vehicle damage factors.

The charts take into account the fact that some commercial vehicles will not travel in the left hand lane. Consequently, if designing a single carriageway road a correction factor needs to be applied in order to take account of the extra vehicle loading due to the availability of only one lane. This factor is given in HD 14/87.

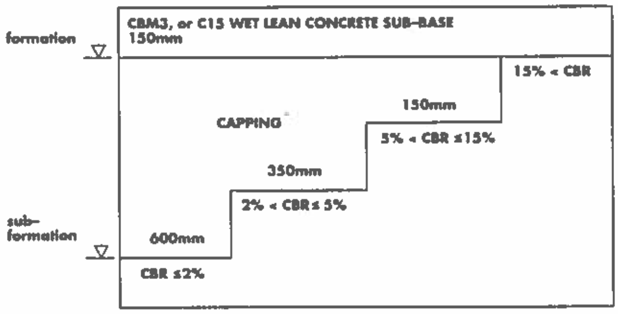
2.4 Foundation Design

The foundation for a concrete pavement must provide a working platform for construction capable of taking construction traffic and must also provide uniform support throughout the life of the pavement so that any maintenance will be confined to the pavement itself.

Sub-grade strength is characterised by California Bearing Ratio (CBR) which is used to determine the thickness of the foundation. The design CBR should be the lower of the long term equilibrium CBR or the value deemed to apply during construction.

The guidance given in HD 14/87 for the design of foundations for rigid and rigid composite pavements is reproduced in Figure 2. The foundation thicknesses given in the Figure for different sub-grade strengths are designed to make an equivalent contribution towards the performance of the completed pavement.

It will be noted that a cement-bound or lean-mix concrete sub-base is always required for a rigid or rigid composite pavement. This was not always a requirement but has been introduced to minimise the risk of water penetrating at the joints and eroding and weakening the sub-base and sub-grade in the long term. Also, cement bound sub-bases permit more effective compaction of the concrete and contribute significantly to the foundation stiffness and the overall load-bearing capacity of the pavement.



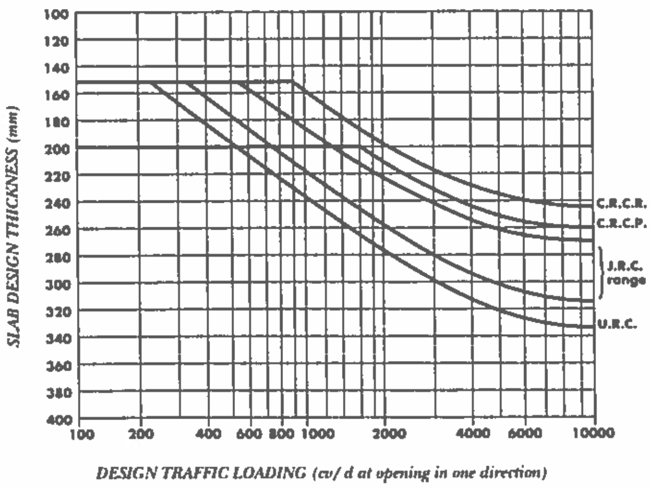
CBM2 or C10 wet lean concrete may be used as sub-base for design traffic loadings less than 700 cv/ d at opening.

Foundation Design (HD 14/87)
Figure 2

A capping layer is required except where very strong sub-grades are available and must consist of granular material or stabilised subgrade.

2.5 Pavement Thickness Design

The thickness design of a concrete pavement is dictated by the forecast in-service traffic. The design curves from the charts in HD 14/87 have been combined by Kennedy (20) in a useful single chart which is reproduced in Figure 3.



Design Curves for Concrete Pavements (HD 14/87)
Figure 3

2.6 Joints

Joints are required in Jointed Unreinforced and Jointed Reinforced construction to minimise the risk of cracking. Joint requirements based on HD 14/87 and the associated specification document "Specification for Highway Works" (21) are given in Table 1 for Jointed Unreinforced construction.

Table 1
Joint Spacings (m) *
Jointed Unreinforced Pavements

Slab Thickness	<225	>225
Contraction Joint	4	5
Expansion Joint	40	60

*All spacings may be increased by 20% if limestone coarse aggregate is used throughout the depth of the slab.

For JRC construction the maximum transverse joint spacing is 30m. Depending on the reinforcement area used a shorter bay length may be required. Every third transverse joint must be an expansion joint.

For construction during the Summer months the Specification (22) permits the exclusion of expansion joints in both Jointed Unreinforced and Jointed Reinforced pavements. The Summer period is defined in the Specification as beginning on 21st April and ending on 21st October. This definition of the Summer period is somewhat arbitrary and given the range of weather conditions known to occur in the U.K. between these dates it would appear that it could be extended in Ireland without cause for concern.

3. SPECIFICATION

3.1 Specification Issues

The Department of the Environment "Green Book" – "Specification for Road Works" (23) was published in 1978 and is based, with adjustments where necessary to suit Irish conditions and materials, on the equivalent U.K. specification.

The author assumes that specification clauses for concrete pavements constructed in Ireland in the 1990's will be based largely on the current U.K. "Specification for Highway Works" noted in the previous Section with possible modifications to suit Irish conditions and materials.

The most important issues in any specification for pavement quality concrete will relate to the following:

- **Characteristics and properties of concrete and its constituent materials.**
- **Joints**
- **Skidding resistance of the pavement**
- **Testing required**

These topics are now briefly discussed in the context of current U.K. specification requirements.

3.2 Characteristics and properties of concrete and its constituent materials

It was noted in the last section on design that pavement life is fundamentally related to concrete strength. The concrete grade now required for pavement quality concrete is Grade 40 with a minimum cement content of 320kg/m^3 and a maximum water:cement ratio of 0.5.

In Ireland the materials standards most likely to be used for the constituent materials of concrete are I.S.1 (1987) (24) for cement, I.S.5 (1974) (25) for aggregates and B.S. 5075 (1982) (26) for admixtures. It should be noted that revisions of both I.S.1 and I.S.5 have been agreed and are likely to be published by N.S.A.I. early in 1991. Also, special requirements as regards skid-resistance of aggregates are likely to be introduced. This issue is dealt with below.

A maximum aggregate size of 40mm is usually allowed in concrete pavements though it is probable that there would be a preference to use 20mm maximum sized material as it is the most widely used size in concrete production in the country and it leads to a mix with better workability and "finishability".

In order to ensure adequate freeze-thaw resistance 5% air-entrainment is usually specified in the top 50mm of pavement where 20mm maximum sized aggregate is used.

The issue of alkali-silica reaction in concrete has been addressed in most specifications in the U.K. in recent years and in many cases restrictions have been placed on the type of cement or aggregates to be used in a project. Guidelines for use in the U.K. on minimising the risk of damaging alkali-aggregate reaction in concrete were published by the Concrete Society in 1987 (27) and, with modifications, have been included in the current issue of the "Specification for Highway Works".

The Irish Concrete Society and the Institution of Engineers of Ireland have been working in Joint Committee since 1988 on producing advice on the subject relevant to the Republic of Ireland. Draft specification guidelines (28) were issued for public comment in October 1990 and the Committee will be presenting its final Report to the Institution and the Society in early 1991 for approval. The author would recommend that where it is deemed appropriate to refer to alkali-silica reaction in specifications for road works in Ireland the advice given in the IEI/ICS document is followed.

The workability of concrete at the point of placing should be such that it can be fully compacted by the paving plant without undue flow. Workability of pavement quality concrete is likely to be very low and would be measured by the Compacting Factor Apparatus rather than the Slump Test.

3.3 Joints

Joints are required in concrete pavements to accommodate volumetric changes in the concrete and also to provide satisfactory junctions between slabs cast at different times and between concrete pavements and other types of pavement.

There are basically five types of joints used in concrete roads:

- **Transverse Contraction Joints**
- **Transverse Expansion Joints**
- **Transverse Construction Joints**
- **Warping Joints**
- **Longitudinal Joints**

Sketches of typical joint details are shown in Figure 4.

Joints are arguably the most important feature of unreinforced concrete pavement construction.

Contraction joints are incorporated in pavement slabs to allow for horizontal movement due to shrinkage in the concrete. They may be wet-formed or sawn. Dowel bars are incorporated at mid-depth in the slab and should be 20 or 25mm diameter depending on the thickness of the pavement layer. Their function is to provide a load transfer mechanism across the joint and they are required to be 400mm long and placed at 300mm centres. The dowels must be debonded over two-thirds of their length.

Expansion joints are incorporated in pavements to accommodate horizontal movement due to thermal effects. They may be substituted by contraction joints if paving is carried out during the Summer months. Joints are full depth and are formed by compressible filler board. Dowels provide load transfer and are 25 or 32mm in diameter depending on the thickness of the slab. They are 600mm in length and placed at 300mm centres. A sheath provides debonding over half the length + 50mm and a tight fitting cap is provided over the end of the sheathed part of the bar.

Construction joints in unreinforced or jointed reinforced slabs will be either contraction or expansion joints.

Warping joints are not a common feature of pavement construction. They allow vertical movement and basically act as a hinge to provide stress relief in particular situations where uncontrolled cracking might occur such as in long narrow slabs. Load transfer in this situation is provided by aggregate interlock. Cracks which form are kept closed by tie-bars.

Longitudinal joints are required parallel to the carriageway centre-line to divide the pavement into acceptable widths. They are wet-formed within the construction width and load transfer is provided by aggregate interlock. The crack which forms is kept closed by means of tie-bars. Polyethylene foam strip is usually used to form the joint and is inserted into the top of the slab using a vibrating plough.

Longitudinal joints are also formed between adjacent slabs cast at different times. In this case tie-bars are cast into the edge of the first slab paved.

Care needs to be taken in detailing longitudinal joints to ensure that they do not fall near the wheel tracks particularly in the most heavily trafficked lane.

Dowel bars in contraction joints and tie-bars in longitudinal joints may be either placed on preformed assemblies or mechanically inserted into the fresh concrete. The Synoptic Table referred to earlier on practices throughout Europe clearly indicates that both methods are used. In the U.K. there has been a ban imposed on the mechanical insertion of reinforcement in other than two layer work. This does not appear to be justified on the basis of continental practice and the author understands that a change in the U.K. position is likely to occur in future revisions of the Specification.

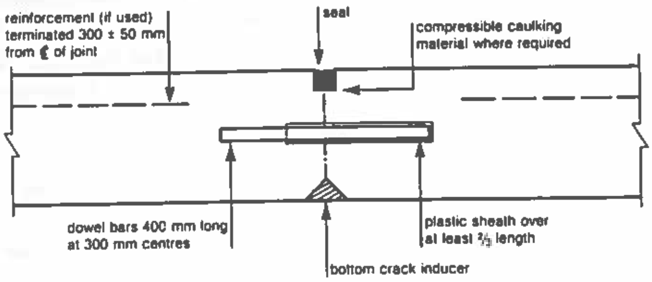
All joints are required to be sealed to prevent ingress of moisture. Hot and cold applied materials or compression seals are used in joint sealing.

3.4 Skidding Resistance of the Pavement

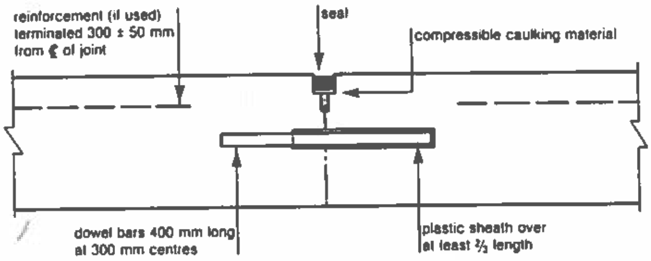
The skid-resistance of the pavement surface is of paramount importance to both the highway engineer and the travelling public. Skid-resistance properties of roads have been directly related to accident statistics and areas of road known to have performed badly on this crucial parameter become well known by the road user.

The factors contributing to the overall skidding resistance of pavements have been studied throughout the world for many decades and have been well documented in an interesting review by MacNicholas (30).

As regards bituminous and concrete surfaces the material properties required for adequate performance are quite different due to the nature of the two materials. Bituminous roads require high polished stone value (P.S.V.) coarse aggregate in a wearing course with a good texture. In concrete surfaces texture and the properties

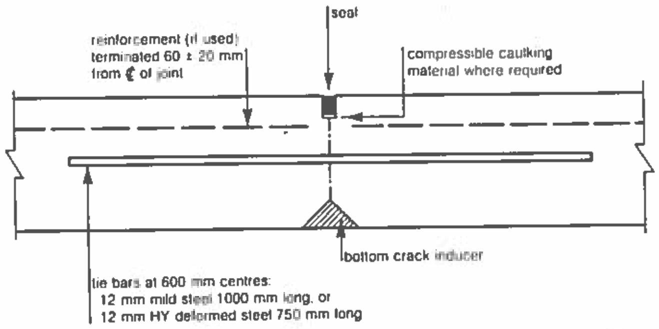


Note: Combined depth of top groove and bottom crack inducer should be between ⅓ and ¼ slab depth

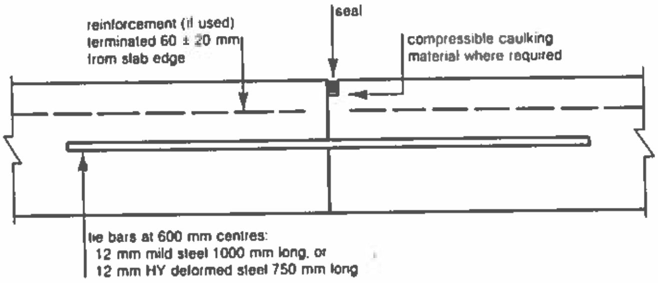


Note: Depth of top groove should be between ⅓ and ¼ slab depth

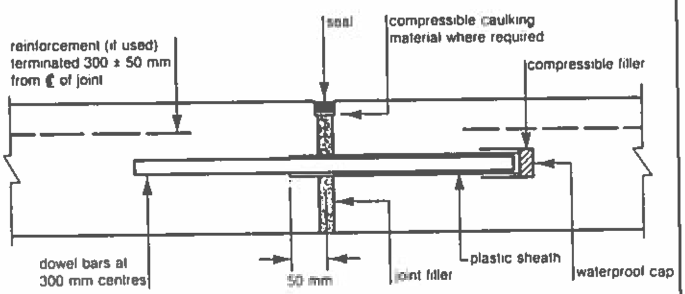
CONTRACTION JOINT



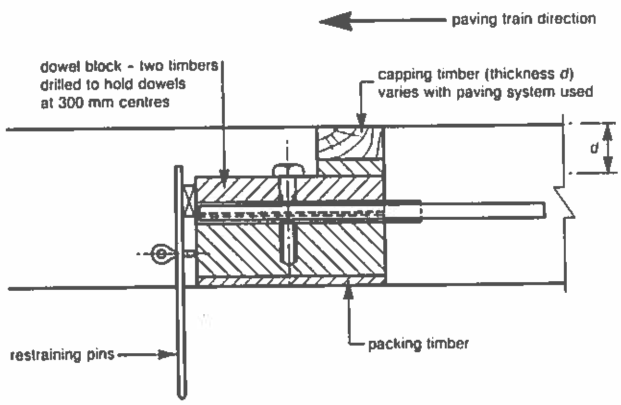
Note: Combined depth of top groove and bottom crack inducer should be between ⅓ and ¼ slab depth



LONGITUDINAL JOINT



EXPANSION JOINT



CONSTRUCTION JOINT STOP-END

Typical Joint Details (29)
Figure 4

of the fine aggregate are the principal factors affecting skid-resistance.

It is now generally accepted that there are two levels of road surface texture associated with skidding resistance - micro-texture and macro-texture.

3.4.1 Micro-texture

In a concrete surface micro-texture is provided mainly by the cement-sand matrix though there may be a small effect from the surface of exposed coarse aggregate. Micro-texture is the basic property required to give good low- speed skid-resistance on a wet pavement surface. It governs penetration of the water film by fine protrusions in the mortar which is essential if the tyre is to maintain frictional contact with the surfacing.

Two restrictions are imposed in the U.K. in relation to the top 50mm of pavement concrete to ensure good micro-texture.

- fine aggregate containing more than 25% acid soluble material may not be used.

- if the coarse aggregate used is limestone then it must have a result of not less than 53 when subjected to the accelerated wear test developed by the U.K. Department of Transport.

It is clear that a hard sand is required for good skid-resistance. It is questionable, however, whether the current U.K. Specification restrictions represent an appropriate strategy for ensuring adequate performance. This issue is worthy of detailed investigation in the Irish context in view of the importance of skidding resistance and the limestone rock origin of a significant proportion of our fine and coarse aggregates.

A review of practices in Europe indicates that the U.K. is the only country that has these two particular requirements in place. They do, however, appear in the Irish 1978 Specification referred to earlier.

Spain and Austria also specify a 'prescription' solution by demanding that the fine aggregate contain more than 30% silica.

A performance based specification clause would be preferable as the restriction on acid soluble material imposed in the U.K. on the fine aggregate does not take into account any distinction between hard and soft rocks. This requirement was introduced to take account of the existence of some weak limestones in the Midlands of England.

A polished mortar test has been investigated in the U.K. with good correlations reported with skid-resistance in practice (31).

It is interesting to note that a recent research report from TRRL (32) does, however, show good correlations between the acid soluble content of the fine aggregate, the results of the polished mortar test and skid-resistance.

Some work has been carried out by Irish industry utilising the accelerated wear test. A number of Irish aggregate combinations have been tested at the Department of Transport in the U.K. The results available to date indicate a clear anomaly which has led those associated with the work to seriously question the relevance of the current use of the test in specifications.

The limited information available from the work to date suggests that the test:

- did not distinguish between Irish limestone and non-limestone coarse aggregates

- is very significantly influenced by the fine aggregate used even though the coarse aggregate dictates whether or not it is a specification requirement to carry out the test.

3.4.2 Macro-texture

The second level of texture – macro-texture – is provided in concrete roads by surface brushing, grooving or aggregate exposure. The primary function of the texture provided is to allow dispersion of water from the rolling tyre and to enable energy to be absorbed in the tread rubber as a result of deformations of the tread by the surface projections. Macro-texture basically allows the low-speed skidding resistance provided by the micro-texture to be maintained at high vehicle speeds.

Macro-texture is generally provided in the surface of concrete pavements by a variety of mechanisms -

- **transverse brushing**
- **longitudinal brushing**
- **exposing the aggregate**
- **dragging burlap**

Concrete certainly has the edge over bituminous surfacing as regards the durability of macro-texture over time. When well formed, macro-texture in concrete surfaces is very resistant to deterioration under traffic.

In the U.K. Specification transverse brushing with a wire-brush is the only mechanism specifically allowed in the production of macro-texture in new pavements. Worn, rain-damaged or inadequately textured surfaces may, however, be textured by grooving.

The texture depth is determined by the sand patch test. An average texture depth of 0.75mm is required when the sand patch test is carried out in a time period between 24 hours and 7 days after the construction of the slab. The test methodology is described in detail in the Specification.

The coarse texture required for high speed skidding resistance brings with it in all road surfaces – both flexible and rigid – the penalty of tyre noise.

There has been considerable research on this issue throughout the world. A seminal Paper on the subject was presented by Salt (33) to the Institution of Civil Engineers in London in 1979.

He showed that for any given texture depth concrete surfaces are noisier than bituminous surfaces but that they are more effective in maintaining high-speed skidding resistance.

In summary, it can be stated that for equal levels of skid-resistance noise levels are also similar.

An interesting development in recent years in Europe has been the use of longitudinal texturing of surfaces which it has been reported gives rise to reduced noise and improved riding quality (34). This form of texturing has actually been used for many years by one Irish Local Authority.

The aggregate requirements discussed above in the context of micro-texture also have a bearing on the integrity of the macro-texture produced. The comments regarding their suitability as appropriate specification parameters are equally applicable in this regard.

Clearly, further work is necessary to establish the real performance of Irish fine and coarse aggregates in the context of overall skid-resistance properties. The U.K. requirements may not be appropriate and industry is currently investigating the matter further in the context of European practice.

Test	**Rate. (The Greater number shall be used)**	
Air content	a. Main slab b. Small slabs less than 300m²	1 per 300m² or 6 per day 1 per 20 m length or 3 per day
Density	a. Main slab b. Trial length	3 Cores per 1200 m length 3 Cores per trial strength
Strength	a. Main slab	1 pair of cubes per 600 m² or 6 pairs per day 1 of each pair tested at 7 days 1 of each pair tested at 28 days Groups of 4 assessed as in BS 5328
	b. Small slabs under 600 m²	4 cubes per 100 m² 2 cubes tested at 7 days 2 cubes tested at 28 days and assessed as in BS 5328
Workability	a. Main slab b. Small slabs less than 300 m²	1 per 300 m² or 6 per day 1 per 20 m length or 3 per day
Hot or cold applied joint sealants	Penetration Test	1 sample per 1000 m of joint or at least 1 per day
Inspection of Dowel alignment	a. Main slab	1 joint per 1500 m length or 1 joint per 5 working days whichever is the sooner
	b. Small slabs c. Trial lengths	At a rate decided by the Engineer 2 consecutive joints If one defective, inspect next 3 consecutive joints
Texture depth	Each lane width	At least one set of 10 measurements per day's work, or more wherever the Engineer considers it necessary

Rates for Sampling and Testing
Table 2

3.5 Testing Required

The successful construction of concrete roads to the required standard requires constant vigilance to ensure that all specification parameters are met within the required tolerances. The rates for sampling and testing recommended by the current U.K. Specification for specific parameters are reproduced in Table 2.

4. CONSTRUCTION

4.1 Construction Methods

Perceptions, common in Ireland, that the riding quality of concrete roads is poor and that noise levels are high, are based almost exclusively on experience with low-speed roads that have been constructed by out-of-date manual methods. The finishing techniques employed and the joint forming and sealing technologies traditionally used in manual construction are not suitable for modern high-speed traffic.

The construction of concrete road pavements using mechanised methods has overcome the problems associated with manual methods of construction. Indeed, the technology of the mechanised construction of concrete roads which has been known and used worldwide for decades continues to improve as plant manufacturers and contractors develop their technology and expertise.

There are basically two methods of mechanised concrete paving – fixed-form and slip-form.

In fixed-form paving the spreading, compaction and finishing of the concrete together with associated operations such as joint formation are carried out between fixed side-forms. The side-forms not only support the edge of the plastic concrete but also support and guide the individual machines making up the paving train.

In slip-form paving, on the other hand, the paving plant incorporates travelling side-forms which only provide edge support to the plastic concrete. Slip-form pavers are usually mounted on caterpillar tracks which travel outside the line of the pavement. Alignment and level are controlled by servo systems operated from preset tensioned guidelines.

Both fixed-form and slip-form methods of construction, when properly employed, are capable of achieving the same high standards of pavement construction. Developments in slip-form technology and the higher outputs achieved with this method have led to a situation now where slip-forming is the method which is used predominantly in most countries. To-date fixed-form paving has been more widely used in the United Kingdom.

4.2 Fixed-Form Construction

A fixed-form paving train consists of a number of individual machines, each normally carrying out one or two basic operations.

The concrete for the pavement slab can be spread and compacted to full depth in a single operation or in two successive layers. Two layer construction allows for possible mix economies as the bottom layer will normally have no special aggregate or air-entrainment requirements.

The choice of single or two-course paving will depend on the particular circumstances of the project. It is interesting to note that the recently constructed Dublin Airport Runway Project was completed, as reported by Clancy (35) and Corcoran (36), using single-course construction even though there were specific specification requirements for air-entrainment and aggregate properties only throughout the top 50mm of pavement.

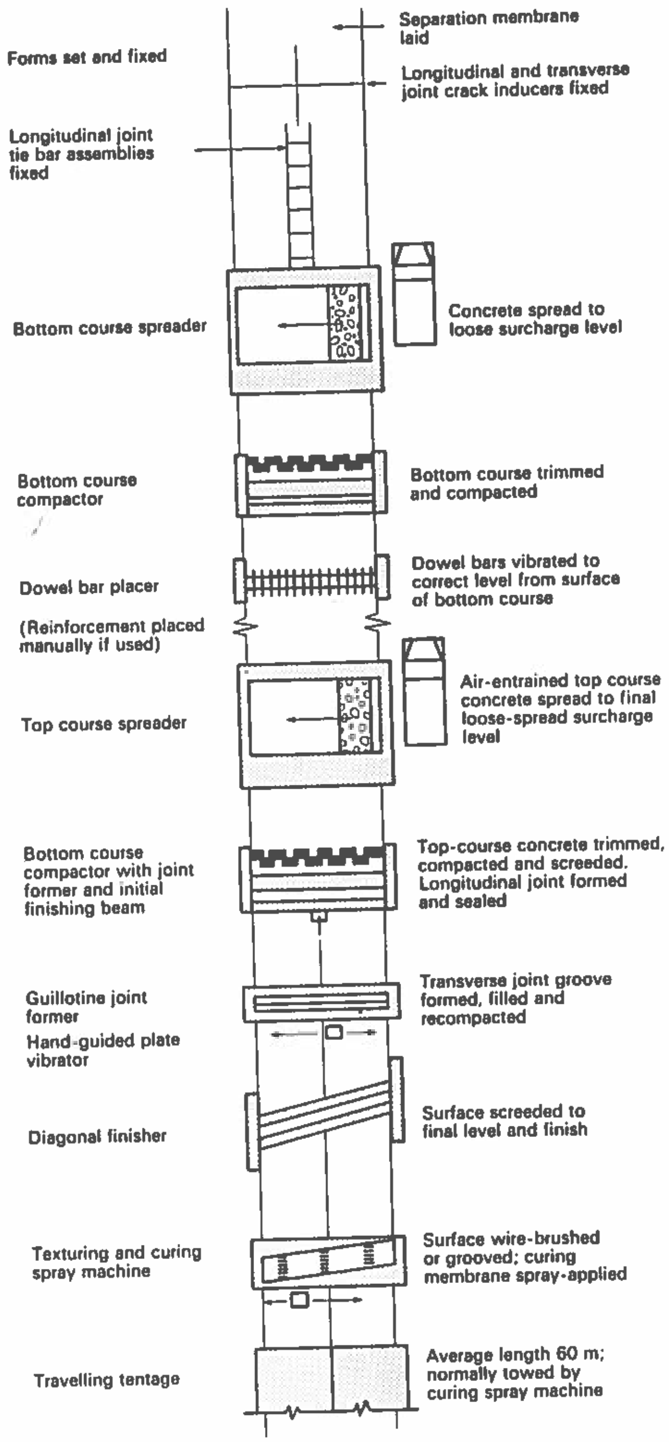
The elements in a typical two-course fixed-form paving train would be:

1. Box – hopper spreader (Bottom Layer)
2. Strike off paddles
Compacting beam
3. Dowel bar inserter
4. Box hopper spreader (top layer)
5. Strike off paddles
Compacting beams
Finishing beam
Longitudinal joint former
6. Transverse groove former
7. Diagonal finisher
8. Texturing machines
9. Curing compound spreader
10. Tentage

These elements are illustrated in Figure 5.

It is worth noting that there is now an increasing tendency towards placement of dowels and tie-bars at joints by mechanical insertion rather than by the use of prefabricated assemblies. The U.K. Specification, however, as noted earlier, does not permit dowels or tie-bars to be inserted into plastic concrete except in two-course work.

Expansion joint assemblies incorporating dowel bars and filler board must by their nature be prefabricated and fixed to the sub-base in advance of concreting.



Typical Fixed-Form Paving Train
Figure 5

Longitudinal tie-bars between abutting slabs may be cranked and held in position at the form face and later bent out at right angles to the slab edge when the fixed-form has been removed. Within the width being paved longitudinal joints are normally formed by inserting an approved preformed strip into the plastic concrete. The strip is fed through a vibrating "plough" mounted on the final compactor.

Transverse joints may be sawed or formed in the plastic concrete. The vibration of a preformed former-filler strip into the plastic concrete represents one methodology for construction.

All transverse joints should be cleaned and sealed after 14 days with hot or cold applied sealants or preformed compression seals. The U.K. Specification lays down clear guidelines on the depths below the surface for joint seals. This requirement is necessary to prevent damage by traffic and also reduces noise.

4.3 Slip-Form Construction

When using slip-form technology the concrete pavement is compacted and finished between moving side forms. The main elements involved in slip-form paving plant are:

1. Paver (including feed & spreading equipment)
2. Transverse joint former
3. Transverse joint finisher
4. Texturing & curing spray machine
5. Tentage (if required)

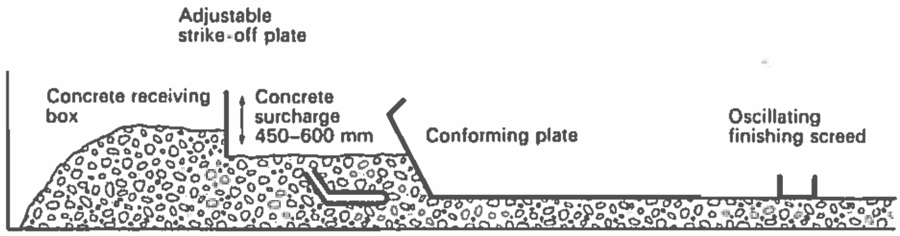
There are two principal types of slip-form paver.

The first type uses a conforming plate. The concrete is compacted and shaped between the sub-base, the side-forms and the conforming plate. The principle of operation which is basically that of extrusion, is shown in Figure 6. A typical layout of plant for a slip-form operation is shown in Figure 7. It should be noted that it is the practice in many countries to incorporate a mechanism for dowel bar insertion for transverse joint dowels and consequently the transverse joint assemblies would not be prefabricated as shown in the Figure.

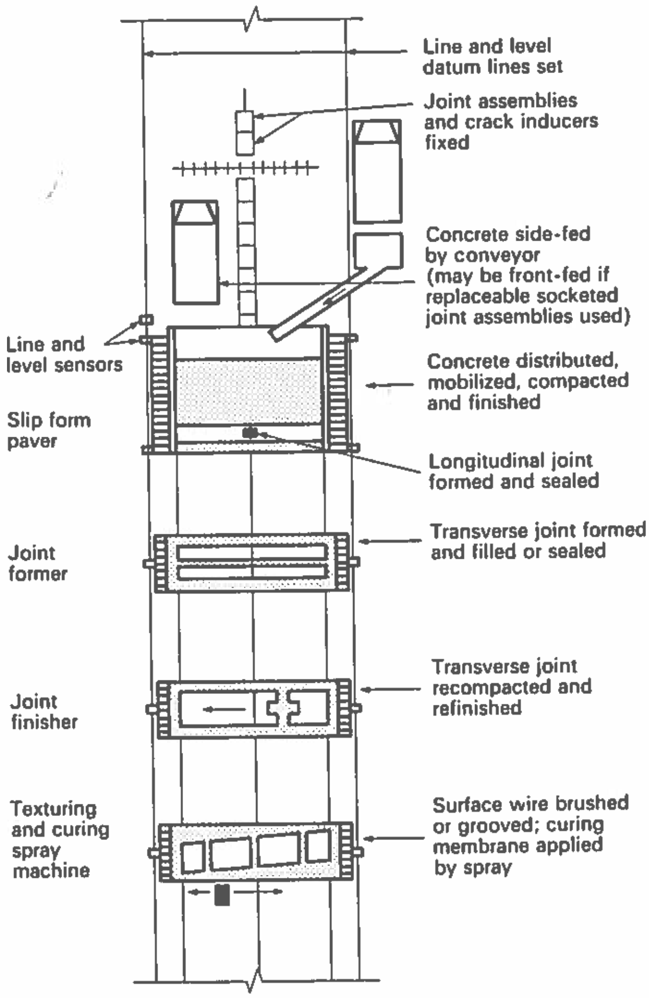
The second type of paver utilises a system of vibrating and oscillating beams which compact and finish the concrete between moving side-forms. The basic principle of the paver operation is shown in Figure 8.

In both types of paver the concrete is fluidised and initially compacted by means of poker vibrators.

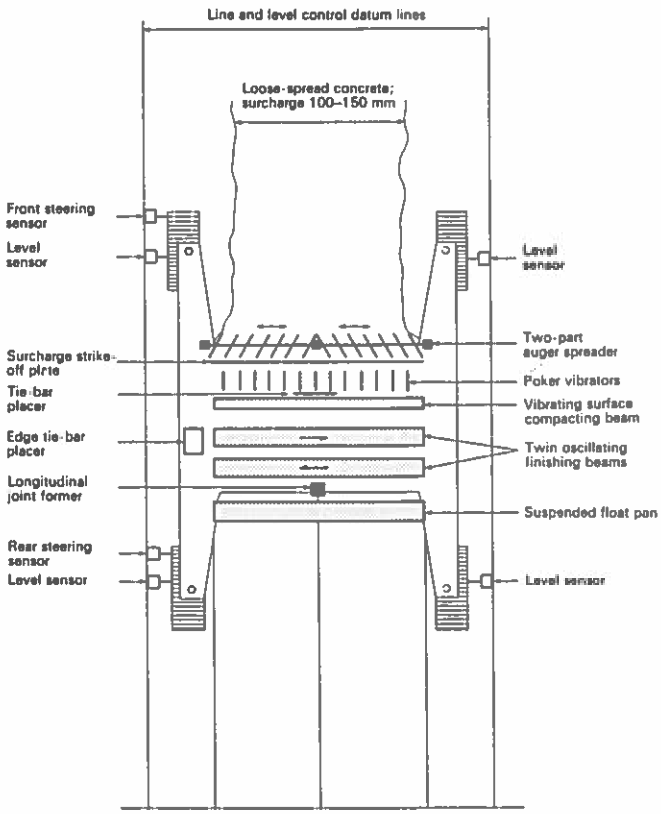
The methods of joint formation and treatment are similar to those for fixed-form construction.



Principle of operation – Conforming Plate Slip-Form Paver
Figure 6



Typical Plant Layout
Slip-Form Paving
Figure 7



Typical Slip-Form Paver-Oscillating Beam Type
Figure 8

4.4 Construction – other aspects

Proper planning is the key to success on any construction project. Matching capacities, with adequate leeway, of paving train, transport system, batching plant and materials' storage systems is fundamental to ensuring that concrete pavements are constructed efficiently without costly delays.

One of the earliest decisions that has to be made by the contractor is what width of paving equipment he will use. This decision will invariably relate to the economics of other aspects of set-up and the result will always be site-specific and will depend in the Irish context on:

- Hire rate of paving equipment
- Cost, availability and capacity of materials storage, batching and transport systems.
- Cross-falls of main carriageway and hard shoulders – similar or different?
- Specification requirements for carriageway and hard-shoulder – similar or different?

The philosophy of one major U.K. contractor outlined by Carroll (37) is interesting to note. In reviewing his own firm's attitude he indicates that "The general philosophy has therefore been to pave the full width of any carriageway to be constructed" and he goes on to describe the principles adopted in paving a number of contracts in the U.K. in recent years from widths of 9.3m to 14.3m in single rips using slip-form equipment.

In the Irish context a two-lane dual carriageway is likely to have a total width of 11.5m (3m hard -shoulder, + 2 No. 3.75m lanes + 1m edge strip). In the author's view it is most likely that a contractor would opt to slip-form the project and the number of rip widths decided on would depend very much on the answers obtained to the questions raised in the listing of issues above.

5. CONCLUSION

Concrete roads have a long history of satisfactory use in many countries and when evaluated on a number of important criteria they offer considerable benefits in the technical and economic arenas. They have made a significant contribution to the evolution of the national road networks of most developed countries and in the interests of competition attitudes in some countries vary from positive discrimination in favour of concrete to at least open tendering on the basis of initial cost alone.

The design and construction principles for concrete roads are well known and will vary only in some aspects of detail, particularly as regards issues of materials specification, from country to country. These issues have been discussed in the preceding Sections of the Paper and some areas that require further work and evaluation in the Irish context have been elaborated.

The benefits of concrete pavements have been well documented by various authors with experience in many countries and can be summarised as follows:

- **Durability** – 40 year design life
- **Safety** – no rutting – less spray
  – not prone to extremes of temperature
  – durable skid-resistant surface
  – excellent visibility characteristics
- **Cost benefits** – lower maintenance costs over the long term (38)
  – lower vehicle fuel costs (39)

It has been argued by Garrett (40) that the only sensible approach to decisions in relation to the design and maintenance of road schemes is to take into account whole-life costing and it would appear that in the U.K., as in some other countries, costs other than the initial construction cost may very well be considered shortly when new road projects are being evaluated. When whole-life costs are taken into account tender prices may be modified by a factor depending on an evaluation of:

- Maintenance costs
- Traffic delay costs due to congestion at future roadworks
- Accident costs at roadworks
- Other accident costs
- Fuel consumption costs
- Residual value

It is interesting to note that cost-benefit analysis and reduction in road accidents are criteria noted as important for the selection of road projects for structural funding from the European Commission (41).

In Ireland currently major road projects go to tender with initial construction cost the paramount factor. As noted in the introduction there are hopeful signs that initial evaluations will shortly take into account the benefits of including as a construction option our primary indigenous building material at the design stage.

The introduction of dual tender policies is likely to lead to greater competition. The solution which gives the lowest initial cost will clearly be contingent on such factors as the timing of the project, the length of the project, the specification parameters adopted and raw material prices prevailing at the particular time. In Ireland, in the context of concrete pavement construction it is most likely that Jointed Unreinforced construction would be the most economical. The Irish Concrete Society Report referred to in the introduction to the Paper showed that, with the particular conditions existing in early 1986, Jointed Unreinforced concrete, even on a first cost basis, was competitive with bituminous construction for projects in excess of 4km in length.

Even if whole-life cost considerations remain an issue for the future a change in current policy on tender options would not only put us in line with our major economic partners but would also hold out the possibility of potential national cost savings in the future.

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