



THE HIGHWAYS AGENCY



THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT



**THE WELSH OFFICE
Y SWYDDFA GYMREIG**



**THE DEPARTMENT OF THE ENVIRONMENT FOR
NORTHERN IRELAND**

The Design of Integral Bridges

Summary: This Advice Note provides guidance on the design of continuous bridges with integral abutments.

REGISTRATION OF AMENDMENTS

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SUPERSEDED

**VOLUME 1 HIGHWAY STRUCTURES:
APPROVAL PROCEDURES
AND GENERAL DESIGN**

SECTION 3 GENERAL DESIGN

PART 12

BA 42/96

THE DESIGN OF INTEGRAL BRIDGES

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1. INTRODUCTION

1.1 Expansion joints in bridge decks are prone to leak and allow the ingress of de-icing salts into the bridge deck and substructure, thereby resulting in severe durability problems. In principle all bridges are to be continuous over intermediate supports and bridges with overall lengths not exceeding 60 metres and skews not exceeding 30° are to be integral with their abutments. (See BD 57, DMRB 1.3). This Advice Note covers the design of integral highway bridges without expansion joints.

1.2 Integral bridges are designed without any expansion joints between spans or between spans and abutments. Resistance to longitudinal thermal movements and braking loads is provided by the stiffness of the soil abutting the end supports and, in some cases by the stiffness of the intermediate supports.

Scope

1.3 This Advice Note is applicable to bridges of steel, concrete and composite construction, including precast and prestressed concrete.

1.4 The Advice Note describes the movements and loads which may be used in the design of integral bridges, and provides requirements for some design details. It supplements the requirements of BD 30 (DMRB 2.2), in respect of integral bridges.

1.5 For bridges with full height frame abutments of overall length up to 15m and cover greater than 200mm, designers may use BD31 (DMRB 2.2).

Definitions

1.6 The following are definitions of terms used in the Advice Note.

i) Asphaltic Plug Joint

An in situ joint in the pavement, complying with BD33, (DMRB 3.4), comprising a band of specially formulated flexible material which may also form the surfacing.

ii) Abutment

The part of a bridge structure that abuts the roadway pavement and formation at the end of a bridge.

iii) Bank Pad Abutment

Bank seat end support for bridge constructed integrally with deck, acting as a shallow foundation for end span and as a shallow retaining wall for adjoining pavements and embankment.

iv) Embedded Abutment

End support for bridge comprising of a diaphragm wall (including contiguous, or secant or sheet pile walls) with toe embedded in ground below lower ground surface.

v) End Screen Abutment

Wall structure cast monolithic with and supported off the end of bridge deck providing retaining wall for adjoining ground, but not acting as a support for vertical loads.

vi) Frame Abutment

End support for bridge constructed integrally with the deck and acting as a retaining wall for adjoining pavement and ground below.

vii) Granular Backfill

Selected granular material placed adjacent to the abutment wall and forming the subgrade for the adjoining pavement construction.

viii) Integral Abutment

Bridge abutment which is connected to the bridge deck without any movement joint for expansion or contraction of the deck.

ix) Integral Bridge

A bridge with integral abutments.

x) Pavement/Abutment interface

The interface between the pavement construction and the back face of the abutment.

xi) Range

Change (of temperature, strain) between extreme minimum and extreme maximum.

xii) Stationary Point

The point on a bridge in plan which does not move when the bridge experiences expansion or contraction during changes in bridge temperature.

xiii) Sub-surface Drainage

A system for draining water from within the surfacing.

xiv) Surface

The carriageway or footway surface.

xv) Surfacing

Carriageway or footway wearing course and base course materials.

Implementation

1.7 This Advice Note should be used forthwith for all schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress. Design Organisations should confirm its application to particular Schemes with the Overseeing Organisation.

2. GENERAL

2.1 Integral bridges should support all the relevant dead loading and live loading including all longitudinal, and in the case of structures which are curved in plan, centrifugal loading, in accordance with BD37, (DMRB 1.3). They should also accommodate the effects of thermal expansion or contraction without excessive deformation of the approach pavements.

Types of Integral Construction

2.2 This Advice Note has been drafted for the types of integral abutment illustrated in Figure 2.1 and described below:

- i) The Frame Abutment which supports the vertical loads from the bridge and acts as a retaining wall for embankment earth pressures. It is connected structurally to the deck for the transfer of bending moments, shear forces and axial loads and supported on foundations. It may be assumed that the abutment will rock bodily on its foundation for the purposes of calculating thermal movements and earth pressure. If the back edge at the top of the abutment is behind the back of the foundation, the design of the pavement/abutment interface should provide for vertical movement of the abutment edge during contraction of the deck.
- ii) The Embedded Abutment, such as a diaphragm wall, which extends to a depth below the retained fill and is restrained against rocking by the length of embedment.
- iii) The Bank Pad Abutment, which acts as an end support for the bridge, moves horizontally during thermal expansion and contraction of the deck. The bank pad must have adequate weight, and the end span have adequate flexibility, to avoid uplift from live loads or from differential settlement.
- iv) The End Screen Abutment acts only as a retaining wall for embankment earth pressures and transfer of longitudinal loads. The vertical loads on the deck are supported by separate supports. These supports are located within 2m of the end screen in order to limit the vertical movement of the end screen when the end span deflects. The end supports may be

isolated structurally from horizontal movements of the end screen, or they may be connected to the deck in which case they must be able to resist, or avoid, the earth pressures arising from their movement relative to the embankment.

Longitudinal Movement

2.3 Bridges should be designed to accommodate the effects of thermal expansion and other longitudinal forces, with thrusts from structural restraints, earth pressures and friction. They should also be designed for the effects of thermal contraction, with axial tension from structural constraint and sliding.

2.4 Multispan integral bridges should not have any expansion joints between spans. Wherever possible, bridge decks should be designed to accommodate the effects of continuity and axial thrust or tension. Various methods for achieving continuity between spans are outlined in BA 57, (DMRB 1.3.8).

2.5 The longitudinal movement of integral abutments should be limited to $\pm 20\text{mm}$ (nominal, 120-year return period) from the position at time of restraint during construction.

2.6 The effects of temperature difference, shrinkage, and creep should be considered in accordance with BS 5400: Part 4⁽³⁾, as implemented by BD 24, (DMRB 1.3.1), and BD 37, (DMRB 1.3).

Load and Material Factors

2.7 Integral bridges should be designed with the load factors specified in BD 37, (DMRB 1.3).

2.8 Earth pressure forces on abutments should be subject to load factors γ_{fl} of

1.5 @ ULS 1.0 @ SLS (BD37, Clause 5.8.1.2)

2.9 Earth pressure coefficients on abutments should be calculated in accordance with BS 8002⁽⁴⁾ using material factors γ_m on earth pressure coefficients of:

disadvantageous forces from backfill $\gamma_m = 1.0$

advantageous forces from backfill when resisting secondary load effects (e.g. braking) $\gamma_m = 0.5$

Thermal Effects

2.10 The characteristic thermal strain (expansion or contraction) throughout the UK can be taken as

steel	(Groups 1 & 2)	± 0.0006
steel with concrete deck	(Group 3)	± 0.0005
concrete	(Group 4)	± 0.00042

For the definition of the above mentioned groups, see Figure 9 of BD 37, (DMRB 1.3). However, the 1.3 factor on the design range of movement at the ultimate limit state given in Clause 5.4.8.1 of BD37, should not be applied to the characteristic thermal strains given above.

2.11 The above characteristic strains are based on the following assumptions:-

i) The bridge spans and abutments are joined during construction at a temperature within $\pm 10^\circ\text{C}$ of the mean between extreme minimum and extreme maximum shade air temperatures as specified in BD37, (DMRB 1.3).

ii) For concrete and composite decks, concrete with a coefficient of thermal expansion of $0.000012/^\circ\text{C}$ has been assumed.

More detailed estimates of thermal strain may be appropriate, based on data in BD37, (DMRB 1.3), if the design specification does not limit the temperature at the time of joining as above, if other materials are used, or if special circumstances apply.

2.12 Lightweight aggregate concrete, and other materials, can have coefficients of thermal expansion

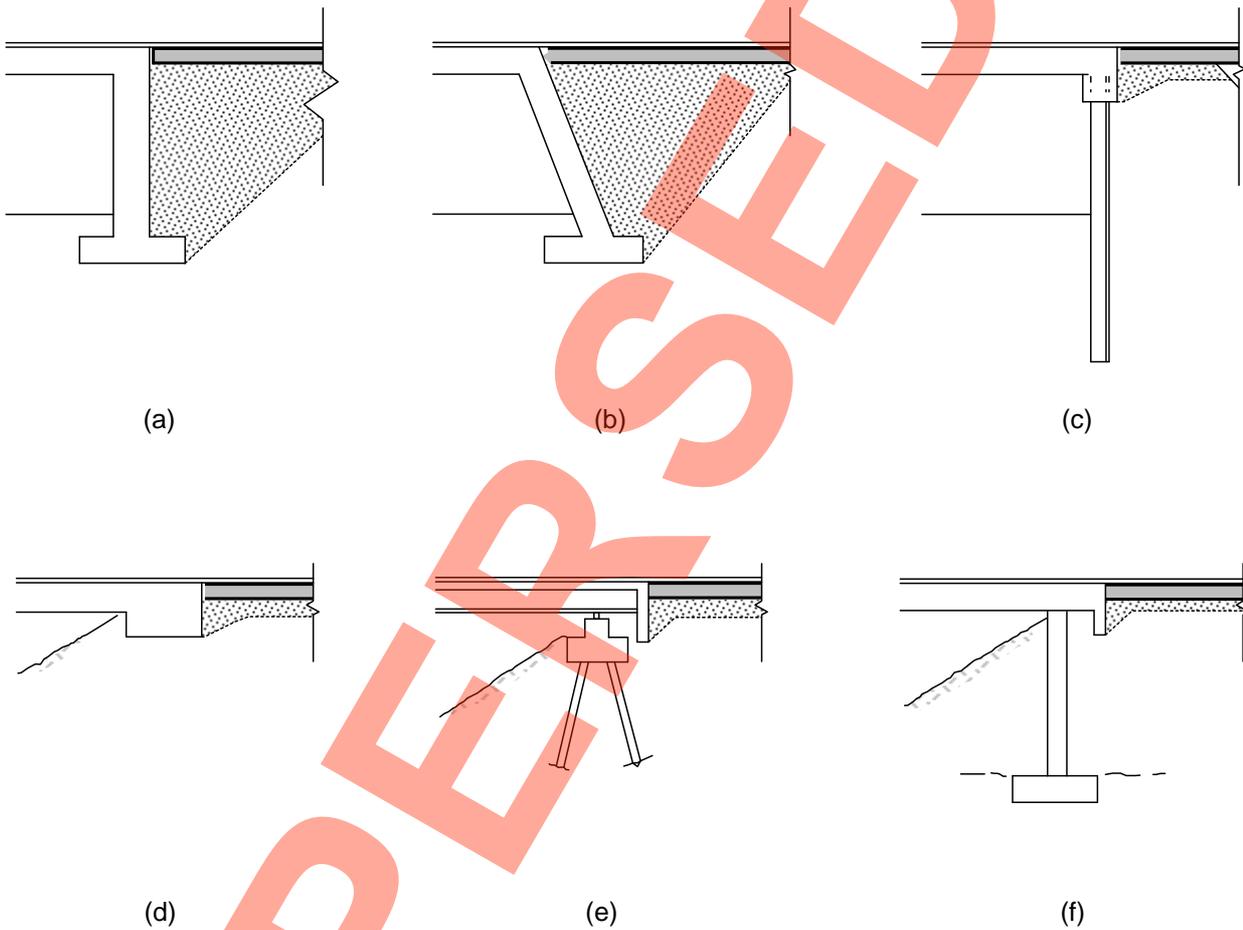
markedly lower than $0.000012/^\circ\text{C}$ and will therefore expand and contract proportionately less than the strains in paragraph 2.10. Where justified, a lower coefficient of thermal expansion may be used in such instances.

2.13 Bridges which are curved, or not symmetric, experience thermal movements relative to a stationary point. The position of the stationary point can be determined from a stiffness analysis employing horizontal stiffnesses at supports and abutments. (See Reference 6).

Piers

2.14 Intermediate supports of integral bridges can be designed to move horizontally with the superstructure or with a bearing which allows lateral movement beneath the deck. In the former case the pier has to be sufficiently flexible to accommodate the thermal movement to which it would be subjected. Designers should be aware of the inherent maintenance problems associated with the use of bridge bearings and make provision for their maintenance and future replacement. For further information see Design for Durability, BA57, (DMRB 1.3.8).

- (a) & (b) Frame abutments. (c) Embedded abutment.
(d) Bank pad abutment. (e) & (f) End screen abutments.



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Figure 2.1 Types of Integral Abutments

3. EARTH PRESSURE

General

3.1 Based on experimental and analytical data the following design recommendations are made for the magnitude of lateral earth pressures to be adopted in the design of integral bridge abutments in the U.K.

Soil Strength and Wall Friction

3.2 An increase of stiffness of granular soil occurs due to densification of the fill under the thermal cyclic movements induced by deck expansion. Even if the fill is placed in loose condition, representative c'_{peak} and ϕ'_{peak} for the fill material, compacted at the optimum moisture content to a dry density of 95% of the maximum dry density determined in accordance with BS 1377: Part 4⁽⁵⁾ using the vibrating hammer method, should be used throughout the design.

3.3 In a conventional retaining wall, following BS 8002⁽⁴⁾, design $\tan\phi'$ would then be calculated using a mobilization factor $M = 1.2$, on representative $\tan\phi'_{peak}$ and applied to calculate active and "at rest" earth pressure coefficients. However, the passive earth pressure mobilised by a granular backfill on an abutment of an integral bridge moving towards the backfill would act in an unfavourable manner. For this reason, the approach of Eurocode 7⁽⁸⁾ Clause 2.4.2 is adopted in which the factor of M is $1/1.2$, ie. a value of < 1 , is applied to representative $\tan\phi'_{peak}$ to determine design $\tan\phi'$ for passive earth pressure calculations. Wall friction should be taken as $\delta = \text{design } \phi'/2$.

Earths Pressure Distribution for Different Structural form

3.4 During displacement towards the backfill, integral abutments with back faces inclined forwards, as in Figure 2.1 (b), mobilise much lower passive earth pressures than vertical walls during displacements; whereas abutments inclined backwards mobilise higher pressures.⁽⁷⁾ K_p also increases very rapidly at high angles of friction ϕ' as follows:

ϕ'	K_p		
	vertical	20° forwards	20° backwards
30°	5	3	7
35°	6	4	12
40°	9	5	20
45°	15	6	37

An underestimate of ϕ' could very seriously underestimate earth pressure loading during thermal expansion. An overestimate of ϕ' could very seriously overestimate the abutment's resistance to longitudinal braking forces. With these caveats and provided that the detrimental effect of using a better quality fill is avoided by site control, there is no need for a further onerous material factor, γ_m . The appropriate γ_m to be applied to passive earth pressure coefficient is given in 2.9.

3.5 A summary of the proposed design earth pressure distributions with depth for the different structural forms is now given. Design of structural elements for serviceability and ultimate limit states should use the appropriate γ_{rl} as given in clause 2.8.

(a) Shallow height bank pad and end screen abutments

3.5.1 The typical height of a bank pad or end screen abutment is about 3m and, therefore, the total force generated by passive excitations is usually readily accommodated within the design. For this reason and because soil shear strains will be high, it is appropriate to assume that full passive pressures will act. Account should also be taken of the mode of movement, ie. rotation, translation, or a combination of the two.⁽⁹⁾

(b) Full height frame abutment

3.5.2 The height of the abutment means that the magnitude of passive pressures acting on the back of the wall is likely to be significant⁽¹⁰⁾. Careful design of the abutment is therefore important to ensure the structure is strong enough to resist lateral pressures that could build up behind the wall, and yet flexible enough to accommodate movement.

3.5.3 For a portal frame structure the earth pressures on the retained side can be represented by a distribution analogous to that employed for calculating compaction stresses in backfill.⁽¹¹⁾ However for integral bridges the use of wall friction will lead to higher earth pressures at the top of the wall which will extend to a greater depth than compaction effects. The suggested distribution (see Figure 3.1) comprises:

- a uniform value of K^* over the top half of the retained height of the wall, with
- lateral earth pressure then remaining constant with depth as K^* drops to K_o and
- below this depth pressures are according to the insitu value K_o .

The following equation which is based on wall friction δ of $\phi' / 2$ has been used to calculate the relationship between K^* , the retained height (H) and thermal displacement of the top of the abutment, (d) :

$$K^* = (d/0.05H)^{0.4} K_p$$

3.5.4 Although it is recognised that this formula is derived from static tests and on its own will lead to an underestimate of stresses in a cyclic situation, allowance for this has been made by adopting suitable soil strength parameters as given in 3.2. However, K^* should not be taken as less than the 'at rest' earth pressure, K_o , nor less than $K_p/3$.

(c) Full height embedded wall abutment

3.5.5 Embedded walls are installed in undisturbed ground and are more likely to be used in clayey conditions. If the clay is over consolidated less movement will be required to mobilise full passive pressures: however this is compensated for by initial concrete shrinkage of the deck which will help to relieve the high insitu soil stresses.

3.5.6 For an embedded wall the earth pressure distribution⁽¹¹⁾ may be represented (see Figure 3.2) by:

- a uniform value of K^* over the top two thirds of the retained height of the wall, with
- lateral earth pressure then remaining constant with depth as K^* drops to K_o
- below this depth pressures are according to the insitu value K_o .

K^* may be calculated in accordance with 3.5.3 and 3.5.4

3.6 Live load surcharge on backfill should be ignored when calculating the passive earth pressure mobilised by thermal expansion of the deck. Earth pressures under live load surcharge in the short term should be checked at 'at rest' earth pressure conditions with

$$K_o = (1 - \sin \phi')$$

where ϕ' is the effective angle of shearing resistance from 3.2

3.7 Active earth pressures on abutments during thermal contraction of the deck are very small as compared to passive pressures and may be ignored.

Backfill

3.8 Backfill material to integral abutments should be free draining selected granular fill with grading and compaction complying with Classes 6N or 6P of Table 6/1 of Specification for Highway Works.

3.9 The backfill to integral abutments should be a designed material with specified properties validated during construction. The specification involves a compromise between stiffness and flexibility. In general granular materials comprising compacted rounded particles of uniform grading can have a peak angle of internal friction, ϕ' , as low as 35°, and may accommodate thermal expansion without high earth pressures. However, they are somewhat vulnerable to settlement. Fill of compacted well graded hard angular particles can have a peak angle of internal friction as high as 55° with very high resistance to thermal expansion and are less vulnerable to settlement. Granular backfill to integral bridges exceeding 40m length should have a peak angle of internal friction ϕ' not greater than 45°, when tested in accordance with the Specification for Highway Works.

3.10 The zone of granular backfill should extend up from the bottom of the abutment wall to at least a plane inclined at an angle of 45° to the wall.

Pavement

3.11 Road pavements should be constructed in accordance with the Specification for Highway Works right up to the back faces of integral abutments. The surfacing can be laid as a continuous layer over the approach roads and over the deck water proofing.

3.12 Asphaltic plug joints complying with BD33 (DMRB 2.3.6) may be used in the surfacing at the interface between the back edges of integral abutments and adjoining flexible pavements.

Drainage

3.13 Gullies should be located in roadside channels on the uphill side at integral abutments to catch surface water that might flow across the pavement/abutment interface.

3.14 Flexible pavements should have a sub-surface drain below the surfacing along the pavement/abutment interface. The sub-surface drainage system should have a fall of at least 2% and shall be easily cleaned.

3.15 Integral abutments should have a permeable backing as specified for earth retaining structures in Specification for Highway Works. The permeable backing should be drained with a pipe of at least 150mm diameter which has a fall exceeding 2% and can be cleaned readily.

Foundations

3.16 Integral abutments can be founded on spread footings or on piles.

3.17 Piles should be designed to accommodate lateral movement and/or rocking of the abutment while supporting axial loads, and to support forces from movements of the piles and/or movements of the ground. Raking piles should not be used for foundations that move horizontally.

3.18 Bearing pressures under foundations which slide while supporting vertical loads, such as bank pads,

should be not greater than 50% of the presumed bearing capacity of the ground for a non-sliding foundation subject to the same loading, in order to avoid settlement during sliding.

Wing walls

3.19 Wing walls attached to abutments should be kept as small as possible to minimise the amount of structure and earth that have to move with the abutment during thermal expansion of the deck. Where large wing walls are used in conjunction with long integral bridges, abutments should be allowed to rock or slide independently from the wing walls.

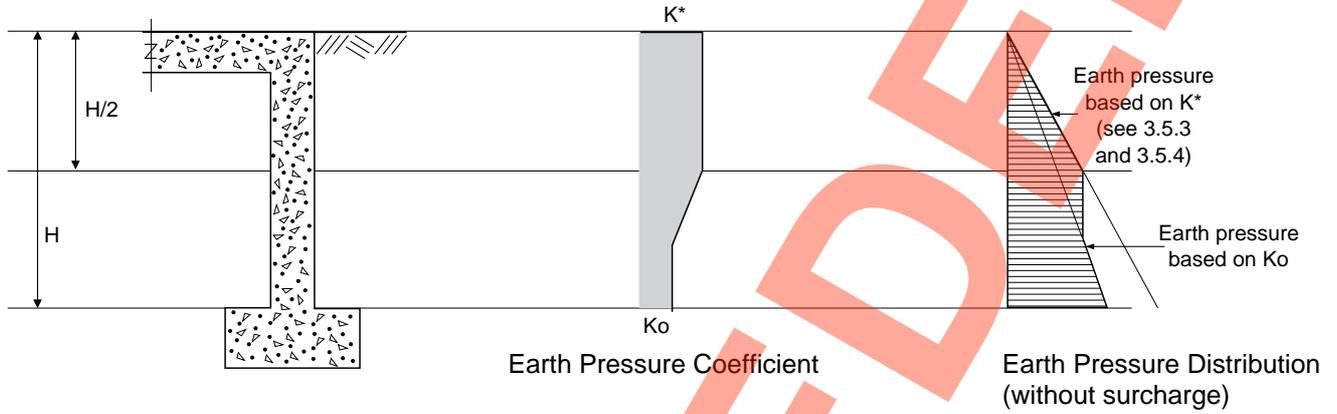


Figure 3.1 Earth Pressure Distribution for Frame Abutment

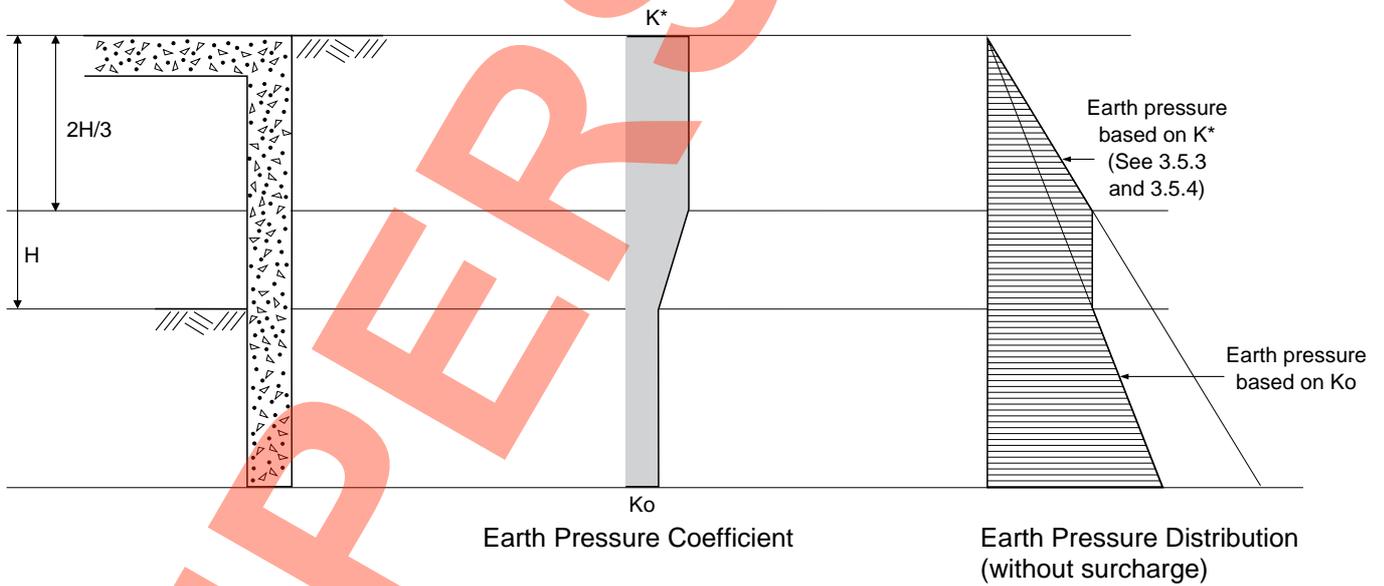


Figure 3.2 Earth Pressure Distribution for Full height Embedded Wall Abutments

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BD30 Backfilled Retaining Walls and Bridge Abutments. (DMRB 1.4)

BD31 Buried Concrete Box Type Structures. (DMRB 2.2)

BD33 Expansion Joints for Use in Highway Bridge Decks. (DMRB 2.3.6)

BD37 Loads for Highway Bridges. (DMRB 1.3)

BD57 Design for Durability. (DMRB 1.3.7)

BA26 Expansion joints for use in highway bridge decks. (DMRB 2.3.7)

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5. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:

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