

PAS 8810:2016

Tunnel design – Design of concrete segmental tunnel linings – Code of practice



hs *engine for growth*



bsi.

Currently in preview, click buy full version

Publishing and copyright information

The BSI copyright notice displayed in this document indicates when the document was last issued.

© The British Standards Institution 2016. Published by BSI Standards Limited 2016.

ISBN 978 0 580 88170 1

ICS 93.060

No copying without BSI permission except as permitted by copyright law.

Front cover photograph: © Crossrail Ltd.

Publication history

First published April 2016

Contents

Foreword	iii
Introduction	v
1 Scope	1
2 Normative references	2
3 Terms, definitions and abbreviations	4
4 Functional requirements	9
5 Conceptual design	14
6 Characterization of ground	18
7 Materials design and specification	23
8 Material characterization and testing	25
9 Limit state design	33
10 Precast concrete segmental lining design	44
11 Concrete segment lining modelling	57
12 Instrumentation and monitoring	72
Annexes	
Annex A (normative) Design management	73
Annex B (informative) Closed-form solutions for static analysis of tunnel lining in soft ground	77
Annex C (informative) Convergence confinement method (CCM) in segment lining design	78
Annex D (informative) Six-stage Gate process	80
Bibliography	81
List of figures	
Figure 1 – Typical fire curves for tunnel design	12
Figure 2 – Typical geometry of precast concrete segment lining	45
Figure 3 – Calculation of taper	47
Figure 4 – Schematic diagram of strain and stress block for reinforced concrete and fibre reinforced section for the development of the M-N envelope	49
Figure 5 – Joint contact width and stress distribution change with joint rotation for flat joint	52

Figure 6 – Joint contact width and stress distribution change with joint rotation for convex-convex joint.....	52
Figure 7 – Simplification of non-uniform load with eccentricity for bursting check on flat joint	53
Figure 8 – Edge spalling schematic	54
Figure 9 – Example of EPDM Gaskets gap pressure curve	54
Figure 10 – Example of a 3D model of a segmental lining with contact elements used at the joints	60
Figure 11 – State of tensile stress of radial and circumferential joints of a segmental lining	61
Figure 12 – Analysis methods for design of tunnels in soft ground	62
Figure 13 – Typical continuum model	63
Figure 14 – Bedded beam spring model	64
Figure 15 – Coefficient of earth pressure change prior (i.e. at rest) and following tunnel construction (variation of horizontal stresses in kPa)..	66
Figure 16 – Typical FE model of a segmentally lined tunnel	67
Figure 17 – Example of a bedded shell model for an opening in a segmental lining with internal temporary support	69
Figure 18 – Example of 3D FE model for junction.....	70
Figure C.1 – Convergence-confinement method – Longitudinal displacement profile (LDP) and ground response curve (GRC) with support characteristic curve.....	78
Figure C.2 – Stress reduction method, conceptual sketch	79

List of tables

Table 1 – Typical elements differentiated from the type of tunnel and associated design issues	9
Table 2 – Tunnel construction methodology and associated typical lining types in soft ground tunnelling	15
Table 3 – Recommendations for durability against chemical attack for the external and internal surface of precast segmental linings where protective lining is not necessary	27
Table 4 – Limiting values of composition and properties for concrete where a DC-class is specified	28
Table 5 – Additional protective measures (APMs)	29
Table 6 – Recommendations for circumstances in which internal lining is necessary for precast concrete segmental linings for tunnels and shafts used for water and sewer services, storage and transportation	29
Table 7 – Typical design situations for precast concrete segmental tunnel lining	34
Table 8 – Typical actions for tunnels in transient design situations	36
Table 9 – Typical actions for tunnels in persistent design situations	38
Table 10 – Typical STR/GEO failure modes of tunnel linings	40
Table 11 – ULS Partial factors on actions	41
Table 12 – ULS Partial factors for materials	42
Table A.1 – Suggested categories for tunnel lining design checking	74
Table B.1 – Closed-form solutions for static analysis of tunnel lining in soft ground	77
Table D.1 – Suggested six-stage Gate process for tunnel lining design ..	80

Foreword

This PAS was sponsored by High Speed Two (HS2) Limited and the British Tunnelling Society (BTS). Its development was facilitated by BSI Standards Limited and it was published under licence from The British Standards Institution. It came into effect on 30 April 2016.

Acknowledgement is given to Hyuk-II Jung, Chris Peaston, Bryan Marsh, Michael Devriendt, Michele Mangione, Eden Almog and Rob Harding of Arup as the technical authors, and the following organizations that were involved in the development of this PAS as members of the steering group:

- Arup
- Atkins
- Balfour Beatty
- British Tunnelling Society (BTS)
- CH2M Hill
- Costain
- Crossrail
- Donaldson Associates
- Dragados
- Health and Safety Executive (HSE)
- Highways England
- High Speed Two (HS2) Limited
- INECO
- London Underground
- Mott MacDonald
- Network Rail
- OTB Concrete
- Skanska
- Thames Tideway
- University College London, Department of Civil Engineering
- UnPS
- VINCI
- Unnamed members

Acknowledgement is also given to the members of a wider review panel who were consulted in the development of this PAS.

The British Standards Institution retains ownership and copyright of this PAS. BSI Standards Limited as the publisher of this PAS reserves the right to withdraw or amend this PAS on receipt of authoritative advice that it is appropriate to do so. This PAS will be reviewed at intervals not exceeding two years, and any amendments arising from the review will be published as an amended PAS and publicized in *Update Standards*.

This PAS is not to be recorded as a British Standard. It will be withdrawn upon publication of its content in, or as, a British Standard.

The PAS process enables a code of practice to be rapidly developed in order to fulfil an immediate need in industry. A PAS can be considered for further development as a British Standard, or constitute part of the UK input into the development of a European or International Standard.

Relationship with other publications

This PAS is expected to be used in conjunction with BS 6164, which makes recommendations for and gives guidance on health and safety practices in tunnel design and construction.

Use of this document

It has been assumed in the preparation of this PAS that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

Copyright is claimed on Figure 12. Copyright holder is The British Tunnelling Society, 5 Churchill Place, Canary Wharf, London, E14 5HU.

Presentational conventions

The provisions of this PAS are presented in roman (i.e. upright) type. Its recommendations are expressed in sentences in which the principal auxiliary verb is "should". The word "may" is used to express permissibility and the word "can" is used to express possibility, e.g. a consequence of an action or an event.

Commentary, explanation and general informative material is presented in italic type, and does not constitute a normative element.

Spelling conforms to The Shorter Oxford English Dictionary. If a word has more than one spelling, the first spelling in the dictionary is used (e.g. “organization” rather than “organisation”).

Contractual and legal considerations

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a PAS cannot confer immunity from legal obligations.

Particular attention is drawn to the following specific regulations:

- Construction (Design and Management) Regulations 2015 [1];
- Construction Products Regulations 2013 [2]; and
- Health and Safety at Work etc. Act 1974 [3].



Introduction

HS2 and BSI engaged with a number of construction industry stakeholders to identify areas in which it was felt that the industry could benefit from further standardization.

PAS 8810 was developed specifically to cover the design of segmental tunnel linings, which was identified as an area in which additional standardization was required. Segmental tunnel linings are currently designed with reference to a large number of published general building standards and industry documents, together with several Eurocodes. However, there is no codified or standardized design document that applies specifically to precast concrete segmental tunnel linings, and the volume of relevant standards, guidance and documentation has led to both conflicting guidance and requirements, and the misinterpretation and misapplication of standards. PAS 8810 therefore aims to bring together existing standards and industry documents into a single, usable standardization document while simultaneously reducing unnecessary administration and delay by streamlining, clarifying and standardizing the design process for segmental lining design.

Clauses 4 to 8 cover the more general aspects of tunnel design and do not restrict the designer to a single construction methodology at the conceptual design stage, as a designer would not limit their scope only to segmental tunnel lining design. Clauses 9 to 17 provide specific, technical information on precast concrete lining elements for segmental tunnel linings.

At the time of publication, the intention is to standardize further areas of tunnel lining design in the near future including sprayed concrete linings and cast-in-situ linings.

As tunnel construction technology is fast changing, some of the recommendations set out in this PAS might not be fully applicable to a newly-introduced technology that does not exist at the time of this PAS publication.

This PAS is not intended to limit the design flexibility or the adoption of new technology, and as such, is not intended to be used as a barrier that prevents the adoption of innovative designs.

A number of other areas were identified as benefitting from standardization. A wider programme of work is underway to develop a further three PASs:

- PAS 8811, *Temporary works – Client procedures – Code of practice* (in preparation), which gives recommendations for UK infrastructure client procedures with respect to temporary works construction projects, from planning through to removal.
- PAS 8812, *Temporary works – Application of European Standards in design – Guide*, which gives guidance on the application of European Standards in the design of temporary works in the UK for practitioners in the fields of structural and geotechnical temporary works design.
- PAS 8820, *Construction materials – Alkali-activated cementitious material and concrete – Specification*, which specifies requirements for alkali-activated cementitious binders for suppliers of alkali-activated binders, ready mixed concrete, engineers and architects, contractors, asset owners and end users.

Currently in preview, click buy full version.

This page is deliberately left blank.

1 Scope

This PAS makes recommendations for the design of concrete segmental tunnel linings. It covers design considerations from project inception through to the end of the service life of the tunnel. At the early stage of the design (e.g. conceptual design stage), the study of the options for the selection of the tunnel lining is not limited to concrete segmental tunnel linings. Thus Clauses 4 to 8 in the PAS are applicable to tunnels with all types of linings. Clauses 9 to 12 give specific recommendations on the design of concrete segmental tunnel linings.

This PAS is for use by design engineers (usually directly employed by the client but this could sometimes be the contractor's designer, for example, in a design and build project) and clients (usually the owner of the tunnel who is responsible for the design and construction of concrete tunnel linings) and contractors.

The PAS sets out detailed design recommendations by referencing existing national standards (BS, BS EN) or internationally-recognized industry standards. Technical requirements from existing standards are referenced, rather than repeated. Specific design recommendations are included only for the design items that are not available from existing standards.

This PAS covers:

- 1) functional requirements;
- 2) conceptual design;
- 3) characterization of ground;
- 4) materials design and specification;
- 5) material characterization and testing;
- 6) limit state design;
- 7) concrete segmental lining design;
- 8) concrete segment lining modelling;
- 9) instrumentation and monitoring; and
- 10) design management.

This PAS does not cover:

- a) sprayed concrete lined tunnels;
- b) cast-in-situ concrete lined tunnels;
- c) any tunnel lining using material other than concrete such as spheroidal graphite iron or steel;
- d) cut and cover tunnels;
- e) drill and blast excavations;
- f) hard rock tunnelling;
- g) pipe jacking; and
- h) project planning and management.

NOTE 1 Recommendations for health and safety practices in tunnel construction are given in BS 6164.

NOTE 2 Requirements for handling ground support elements are given in BS EN 16191.