13 EFFECT OF UNDERGROUND STRUCTURES ON EXISTING STRUCTURES

13.1 GENERAL

13.1.1 Introduction

1 This Part describes the Risk Assessment process, i.e. the required minimum steps to assess the effect of underground structures on the surrounding existing structures. It is applied on structures located within the Influence Zone of the underground structure as it is defined in 13.2.2 of this Part.

13.1.2 References

1 The following standards are approved and/ or referred to in this Section:

EN 1998 ....Eurocode 8: Design of structures for earthquake resistance:

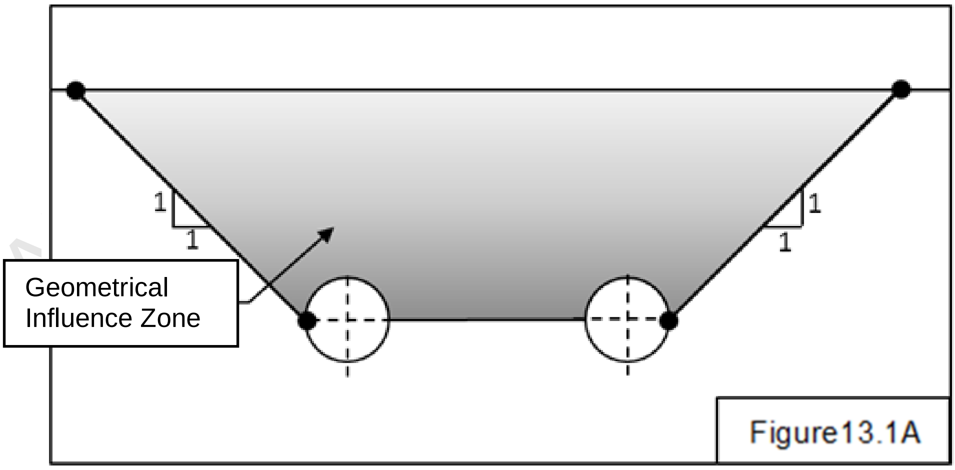
EN 1998-1 ....Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings

13.2 DEFINITIONS

13.2.1 Geometrical Influence Zone

1 The Geometrical Influence Zone is defined by the following minimum geometrical requirements:

(a) For the tunnels:



(b) For the rest of the underground structures:

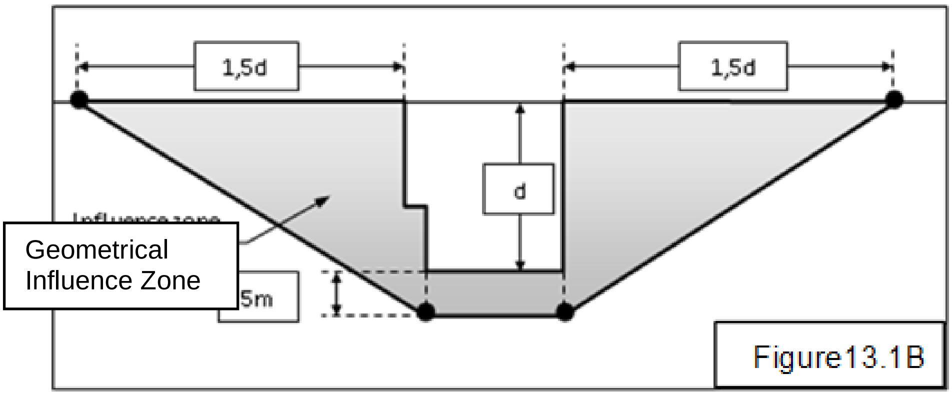


Figure13.1B

13.2.2 Influence Zone

1 The Influence Zone is the Geometrical Influence Zone limited by the contour of 5 mm settlement (settlement equal to or above 5 mm is considered), unless the Designer needs to consider smaller values of settlement as well. At the junction of underground structures (e.g. tunnels to station box, underpasses to station boxes, cross passages to tunnels) the combined effect of the excavated structures should be considered.

(a) For the tunnels:

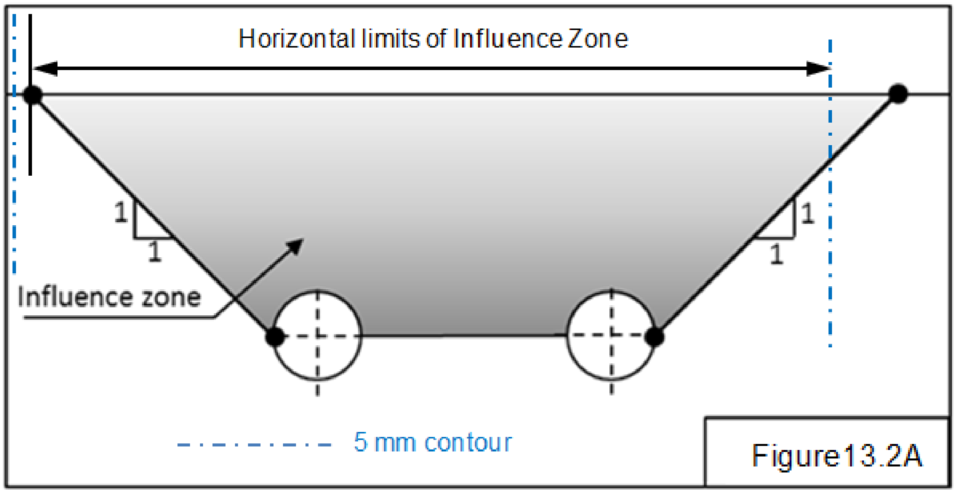


Figure13.2A

(b) For the rest of the underground structures:

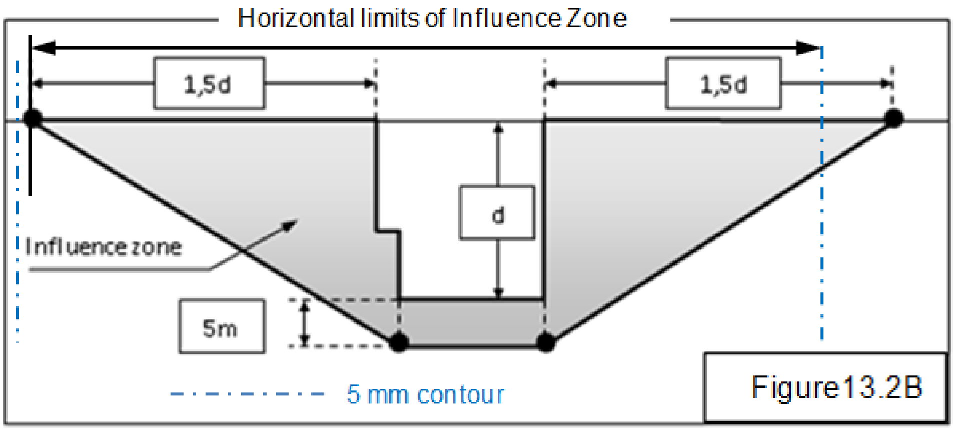


Figure13.2B

13.2.3 High Rise Buildings

1 High rise buildings are defined as those structures that have a height of more than 30 meters above ground.

13.2.4 Buildings Importance Classes – Importance Factors

1 EN 1998-1 (Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings) classifies the buildings in 4 importance classes, depending on the consequences of collapse for human life, on their importance for public safety and civil protection and on the social and economic consequences of collapse. Based on this and on the relevant table 4.3 of EN 1998-1, the definitions of the importance classes of buildings are given in the following table:

Table 13.1: Importance Classes for Buildings

Importance Class	Buildings	Importance Factor γ_I	Building is:
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.	0.8	Of minor importance
II	Ordinary buildings, not belonging in the other categories.	1.0	Ordinary
III	Buildings that are of importance in view of the consequences associated with a collapse, e.g. mosques, schools, assembly halls, cultural institutions, monuments, etc.	1.2	Important
IV	Buildings whose integrity is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.	1.4	Vitally Important

13.2.5 Population Factor

1 The Population Factor γ_P is a factor that considers the number of users of a building. It is equal to 1.00 if the number of users is less than 100 and equal to 1.15 if the number of users is at least 100.

13.2.6 Importance Coefficient

1 The Importance Coefficient C_I is the product of the Importance Factor and the Population Factor: $C_I = \gamma_I \times \gamma_P$

13.2.7 Buildings Sensitivity

1 The buildings sensitivity designation is based on the initial category of Damage of the buildings according to 13.3 (2) of this Part. The building is considered as:

(a) Of low sensitivity, if its initial Category of Damage is 0, 1 or 2.

(b) Sensitive, if its initial Category of Damage is 3.

(c) Very sensitive, if its initial Category of Damage is 4 or 5.

13.2.8 Vulnerability Index

1 The Vulnerability Index I_V is a numerical index which primarily depends on the building structural system, but also considers other characteristics of the building as they are recorded in the Existing Structures Register (see next chapter in this Part). The calculation of the Vulnerability index is presented in the Annex A

13.2.9 Risk Coefficient

1 The Risk Coefficient C_R is the product of the Importance Coefficient and the Vulnerability Index rounded up to the higher integer in case of a decimal number: $C_R = C_I \times I_V$

13.3 EXISTING STRUCTURES REGISTER

1 A register of the existing structures within the Influence Zone should be created prior to the execution of works. This register should as a minimum include:

(a) A General Layout drawing which will include:
- (i) the location and arrangement of the underground structures
- (ii) the limits of the Geometrical Influence Zone
- (iii) the settlements contours
- (iv) the limits of the Influence Zone
- (v) the existing structures within the Influence Zone with numbering for each structure

(b) A report with the following information about each existing structure:
- (i) the age of the structure
- (ii) its use (e.g. mosque, residential building, school, footbridge, hospital, cultural institution)
- (iii) in case of buildings if it is a private, Governmental or Administrative building
- (iv) its foundation type
- (v) any known subsoil problems (e.g. wells, karstic voids)
- (vi) its dimensions in a schematic plan view and its height above ground
- (vii) the type of its structural system (e.g. reinforced concrete frames, steel structure)
- (viii) a layout of its vertical structural elements
- (ix) its height above ground
- (x) the number of underground stories / basements for buildings
- (xi) information on any interventions to the structural system
- (xii) information on possible extensions to length and height
- (xiii) the number of sides on which a building has contact with other buildings/structures
- (xiv) information of the existence of a ground floor storey with big height (at least 1.5 times that of a typical storey of the building) for buildings
- (xv) history of damages to the bearing system and/or to the filling elements
- (xvi) the location depth, cross sections and materials properties in case of utilities

(xvii) statement if the above information was provided by word of mouth or by means of official documents

(xviii) photos of the structure (where possible) including all faces in case of a building

2 The structures are then assigned an initial Category of Damage based on their initial condition by using the table 13.2. Initial condition is the condition of the buildings prior to the excavation works of the underground structures or the tunnelling works.

13.4 STRUCTURES RISK ASSESSMENT FLOWCHART

1 The Risk Assessment of the surrounding structures within the Influence Zone shall be carried out according to the flowchart in the Annex A.

2 For the description of the processes, structures types and risk assessment stages see next chapter in this Part.

13.5 STRUCTURES RISK ASSESSMENT DESCRIPTION

13.5.1 General

1 Two separate processes are defined depending on the Type of the structure examined:

(a) Type I structures: buildings and other structures which possess rigidity and thus cracking may develop based on their bending and shearing stiffness and from any additional pure tension;

(b) Type II structures: major road pavements and utilities (flexible structures with negligible flexural and shear stiffness) in which cracking can develop due to pure tensile stresses caused by elongation.

13.5.2 Type I Structures – Risk Assessment

1 The Risk Assessment for each structure is carried out in three consecutive Stages, according to the Category of Damage each structure can tolerate or may suffer during the excavation works of the underground structures or the tunnelling works. The categories of Damage are described in the following table:

Table 13.2: Classification of visible damage to walls with particular reference to ease of repair of plaster and brickwork or masonry

Category of Damage	**Degree of Severity**	**Description of typical damage** **Note:** Crack width is only one factor in assessing Category of Damage and shall not be used on its own as direct measure of it.
0	Negligible	Hairline cracks less than about 0.1 mm
1	Very slight	Fine cracks which can easily be treated during normal decoration. Perhaps isolated slight fracturing in building. Cracks rarely visible in external brickwork. Typical crack widths up to 1 mm.
2	Slight	Cracks easily filled. Re-decoration probably required. Recurrent cracks can be masked by suitable linings. Cracks may be visible externally and some repointing may be required to ensure weather tightness. Doors and windows may stick slightly. Typical crack widths up to 5 mm.
3	Moderate	The cracks require some opening up and can be patched by a mason. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired. Typical crack widths are 5 to 15 mm or a significant number of cracks up to 3 mm.
4	Severe	Extensive repair work involving breaking-out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably. Some loss of bearing in beams. Service pipes disrupted. Typical crack widths are 15 to 25 mm. Number of cracks to be taken into account as well.
5	Very Severe	This requires a major repair job involving partial or complete re-building. Beams lose bearing and walls lean badly and require shoring. Windows broken with distortion. Danger of instability. Typical crack widths are greater than 25 mm. Number of cracks to be taken into account as well.

2 Each structure is assigned to a Risk Assessment Stage as per the below table:

Table 13.3: Assignment of Structures to Risk Assessment Stages

Risk Assessment Stage	**Structures Assigned**	**Further actions based on the results**
1	All buildings, bridges and rigid utilities located within the Influence Zone	- If the calculated differential settlements and slopes meet the limits for Category of Damage 0 or 1, no further assessment is required. The structure shall be marked with GREEN coloured fill in the General Layout drawing described in 13.3 1. - If the calculated differential settlements and slopes meet the limits for Category of Damage 2 or 3, the structure shall be assigned to Stage 2 and shall be marked with YELLOW coloured fill in the General Layout drawing described in 13.3 1.

<table>
<tr><th>Risk Assessment Stage</th><th>Structures Assigned</th><th>Further actions based on the results</th></tr>
<tr><td></td><td></td><td>- If the calculated differential settlements and slopes meet the limits for Category of Damage 4 or 5, the structure shall be assigned to Stage 2 and shall be marked with RED coloured fill in the General Layout drawing described in 13.3 1.</td></tr>
<tr><td>2</td><td>All buildings, bridges and rigid utilities that:
➢ Have exceeded the limit values for Category of Damage 0 or 1 during Stage 1.
➢ Are high rise buildings
➢ Are sensitive or important buildings</td><td>- If the calculated equivalent tensile strains meet the limits for Category of Damage 0, 1 or 2, no further assessment is required. The structure shall be marked with GREEN coloured fill and an outer thick border indicating its colour designation during Stage I Assessment in the General Layout drawing described in 13.3 1. Example: YELLOW in Stage 1, GREEN in Stage 2:

- If the calculated equivalent tensile strains meet the limits for Category of Damage 3, the structure shall be assigned to Stage 3. The structure shall be marked with YELLOW coloured fill and an outer thick border indicating its colour designation during Stage I Assessment in the General Layout drawing described in 13.3 1.
- If the calculated equivalent tensile strains meet the limits for Category of Damage 4 or 5, the structure shall be assigned to Stage 3. The structure shall be marked with RED coloured fill and an outer thick border indicating its colour designation during Stage I Assessment in the General Layout drawing described in 13.3 1.
<u>All structures in Stage 2 shall be monitored during construction.</u></td></tr>
<tr><td>3</td><td>All buildings, bridges and rigid utilities that:
➢ Have exceeded the limit values for Category of Damage 0, 1 or 2 during Stage 2.
➢ Are founded on piles located at a distance smaller than one tunnel diameter from the tunnel lining.
➢ Are very sensitive or vitally important</td><td>- If the Finite Elements analysis results meet the limits for Category of Damage 0, 1 or 2 of Stage 2 the structure shall be monitored during construction.
- In any other case the structure shall be reinforced / protected and / or the ground has to be improved to the point that the Finite Elements analysis results meet the limits for Category of Damage 0, 1 or 2 of Stage 2. The structure shall be monitored during construction.</td></tr>
</table>

13.5.3 Type I Structures – Stage 1 Risk Assessment

1 In this Stage the Risk Assessment shall be carried out based on the calculated values of the differential settlements of the structure at its foundation level and the corresponding slopes, without assuming soil-structure interaction (green-field conditions). Then these values shall be compared to the limit values that correspond to each Category of Damage. The initial limits are given in the below table:

Table 13.4: Initial Limit Values for Differential Settlements and Slopes and Corresponding Category of Damage

Category of Damage	Initial Limit Values for the Differential Settlement of the Structure ΔS_{max} (mm)	Initial Limit Values for the Slope $(\Delta S/L)_{max}$
0 to 1	ΔS_{max} ≤ 10	$(\Delta S/L)_{max}$ ≤ 1/500
2	10 < ΔS_{max} ≤ 50	1/500 < $(\Delta S/L)_{max}$ ≤ 1/200
3	50 < ΔS_{max} ≤ 75	1/200 < $(\Delta S/L)_{max}$ ≤ 1/50
4 to 5	75 < ΔS_{max}	1/50 < $(\Delta S/L)_{max}$

2 The above initial limits shall be reduced depending on the value of the Risk Coefficient C_R of the structure. The reduced limits are given in the below two tables:

Table 13.5.1: Reduced Limit Values for Differential Settlements and Slopes for Reinforced Concrete, Steel and Composite Buildings as well as Structures with Prestressed Concrete Elements

Risk Coefficient (C_R)	Reduced Limit Values for the Differential Settlement of the Structure ΔS_{max} (mm)	Reduced Limit Values for the Slope $(\Delta S/L)_{max}$
C_R ≤ 30	No reduction	No reduction
30 < C_R ≤ 120	Reduce initial limit values by 5%	Reduce initial limit values by 5%
120 < C_R ≤ 210	Reduce initial limit values by 10%	Reduce initial limit values by 10%
210 < C_R	Reduce initial limit values by 15%	Reduce initial limit values by 10%

Table 13.5.2: Reduced Limit Values for Differential Settlements and Slopes for Structures with Load Bearing Masonry

Risk Coefficient (C_R)	Reduced Limit Values for the Differential Settlement of the Structure ΔS_{max} (mm)	Reduced Limit Values for the Slope $(\Delta S/L)_{max}$
C_R ≤ 30	Reduce initial limit values by 10%	Reduce initial limit values by 10%
30 < C_R ≤ 120	Reduce initial limit values by 15%	Reduce initial limit values by 15%
120 < C_R ≤ 210	Reduce initial limit values by 20%	Reduce initial limit values by 20%
210 < C_R	Reduce initial limit values by 25%	Reduce initial limit values by 25%

3 At the junction of underground structures (e.g. tunnels to station box, underpasses to station boxes, cross passages to tunnels) for the calculation of the settlements and thus the differential settlements the combined effect of the excavated structures should be considered.

13.5.4 Type I Structures – Stage 2 Risk Assessment

1 In this Stage the Risk Assessment shall be carried out based on the values of the calculated maximum total tensile strain that develops in the structure due to its bending and shear stiffness plus horizontal tensile strain. Then these values shall be compared to the limit values that correspond to each Category of Damage. The initial limits are given in the below table:

Table 13.6.1: Initial Limit Values for Maximum Total Tensile Strains and Corresponding Category of Damage

Category of Damage	Initial Limit Values for the Maximum Total Tensile Strain of the Structure ε_{max} (%)
0	0.000 < ε_{max} ≤ 0.050
1	0.050 < ε_{max} ≤ 0.075
2	0.075 < ε_{max} ≤ 0.150
3	0.150 < ε_{max} ≤ 0.300
4 to 5	0.300 < ε_{max}

2 The above initial limits shall be reduced depending on the value of the Stage 2 Risk Coefficient C_R of the structure. The reduced limits are given in the below table:

Table 13.6.2: Reduced Limit Values for Maximum Total Tensile Strains

Stage 2 Risk Coefficient (C_R)	**Reduced Limit Values**
$4 \leq C_R \leq 20$	Reduce initial limit values by 5%
$20 < C_R \leq 35$	Reduce initial limit values by 10%
$35 < C_R \leq 50$	Reduce initial limit values by 15%
$50 < C_R \leq 65$	Reduce initial limit values by 20%

13.5.5 Type I Structures – Stage 3 Risk Assessment

1 In this Stage a detailed analysis should be carried out considering geomaterial-structure interaction and three-dimensional aspects. The presence and current condition of the building and the ground should be considered and modelled as well as the detailed geometry and the construction sequence of the excavation pit and / or the tunnelling sequence. For evaluation of results and further action see flowchart in Annex A.

2 In case any reinforcing / improving measures are decided, a new analysis as the one described in (1) should be carried out considering them (see flowchart in Annex A). For evaluation of results and further action see flowchart in the Annex A.

13.5.6 Type II Structures – Risk Assessment

1 This Risk Assessment is applicable for roads, road pavements and flexible utilities which may suffer from cracking due to tensile stresses cause by elongation. For these structures, the maximum tensile strain should be calculated and compared to the limiting values given in the below table:

Table 13.7: Limit Values for Tensile Strain due to Elongation

Structure	**Serviceability Limit (SL)**	**Ultimate Limit (UL)**
Cast iron, concrete lining	0.03%	0.10%
Steel	0.05%	0.10%
Ductile cast iron	0.10%	0.20%
Plastic materials	0.70%	2.00%
Telecommunication cables (copper or fibre optics)	0.05%	0.10%
Road pavements (asphalt)	0.75%	1.00%

2 For evaluation of results and further action see the flowchart in Annex A.

END OF PART

ANNEX A

Effect of Underground Structures on Existing Structures