Periphery trench for reducing the impact of surface subsidence on structures

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Abstract

Tunnel excavations, underground mines and the collapse of abandoned shallow natural cavities induce a surface subsidence. The existing structures and infrastructures can be damaged by the strain and settlement of the soil in the subsided zone. Different strategies can be used to deal with the subsidence hazard before, during and after the subsidence occurrence. Some mitigation methods exist for reducing the impact of the subsidence on the existing structures. One of them is the periphery trench. The method consists in cutting the soil around the existing building then filling the trench with a compressible material. The effect of horizontal strain will be absorbed by the partial closure of the trench. Numerical methods (2D and 3D, finite element method and distinct element methods) are used to evaluate the optimal dimensions and the position of the periphery trench according to the magnitude of subsidence, the relative position of the settlement trough and the structure and the nature of the structure itself (mainly the position of the foundation). In addition, the numerical methods are used to determine the characteristics of the filling materials that can be recommended. A numerical parametric study has been carried out focussing mainly on the Young modulus of filling material. The numerical modelling results show clearly that the trench is efficient when the building is located on the compression zone of the subsidence. Moreover the distance between the trench and the foundation should be greater than one meter. The filling material must have a Young modulus ranging from 1 to 10 % of the Young modulus of soil.

Keywords: Tunnels, mines, subsidence, damage, mitigation, trench

1 SUBSIDENCE DESCRIPTION AND CONSEQUENCES

1.1 Subsidence Mechanism and Components

Subsidence is a vertical displacement of the ground surface over areas where mineral ores were removed. Subsidence causes ground surface deformation resulting in a range of problems from deep holes with vertical sides that pose physical threats to people, to more subtle forms of subsidence characterized by sagging of the ground surface producing more damage, over larger areas, affecting nearly all manmade structures. The subsidence breaks up classically into a vertical movement of the ground, called subsidence, and a horizontal displacement (Peck, 1964, Standing, 2008, Al Heib, 2008). All forms of slope (tilt and strain) are calculated as the difference in subsidence and horizontal displacements between two points close together divided by their distance apart. Figure 1 presents the theoretical curves of vertical displacement, horizontal displacement, tilt, horizontal strain and curvature for an underground mine. Traditionally, only the vertical displacements are obtained by direct survey measurements, the others parameters are estimated using empirical and analytical approaches (Lack et al., 1992, Deck et al., 2003). The subsidence characteristics depend on the characteristics of underground cavities (depth, surface, etc.). The influence angle γ determines the limit impact of subsidence on structures and infrastructures. The influence angle corresponds to the vertical direction and the line that connects negligible subsidence point to the edge of the underground voids form this angle. The maximum damages observed on structures are located in the zone of maximum horizontal extension strain defined by the angle θ (Figure 1).

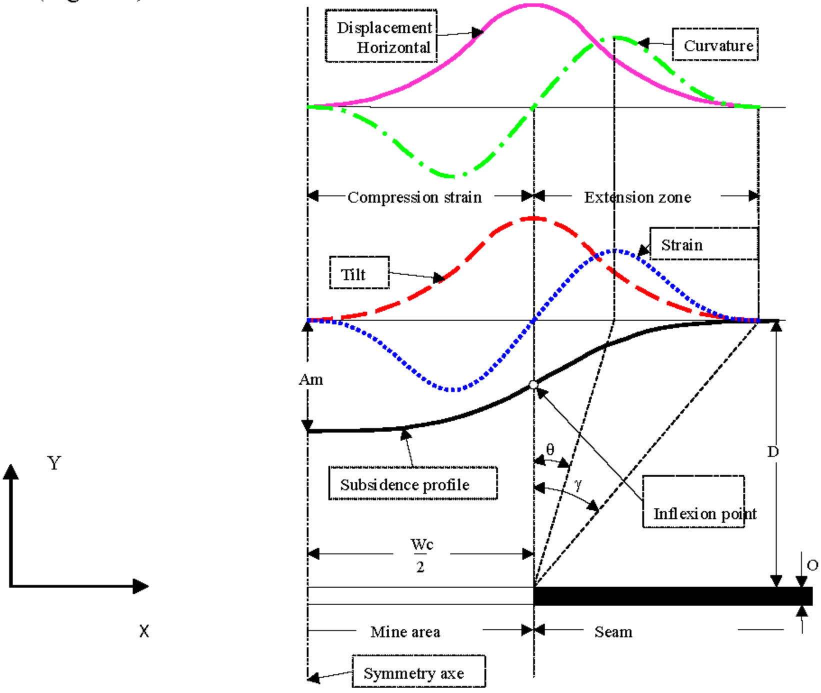

Figure 1: Subsidence Parameters (O: layer open, Am: maximal subsidence, γ and θ: influence angle and maximum strain angle, D: depth, Wc: critical width)

1.2 Damages of Structures

The influence of subsidence on buildings and infrastructures has become an important and costly environmental issue during mining and after the closure of mines (Edjossan-Sossou et al., 2012). The figure 2 shows the effect of compression strain on an existing structure. The trench plays a role in this case of situation to reduce the damage level.

The figure 3 idealizes the different movements that can affect the structure due to surface subsidence. The vertical component of ground movements (subsidence) causes changes in ground gradient, which can adversely affect, for example, drainage, tall buildings and machinery in factories. The tilt, horizontal strains (extension and compression) and curvature are the causes of the most commonly observed type of subsidence damage. Extension is characterized by the pulled open joints in masonry. The compression strain results in the: squeezing-in of voids such as doors and windows and the horizontal movements of masonry blocks.

Figure 2: Example of serious structure damages due to subsidence – Iron mine – Lorraine – France

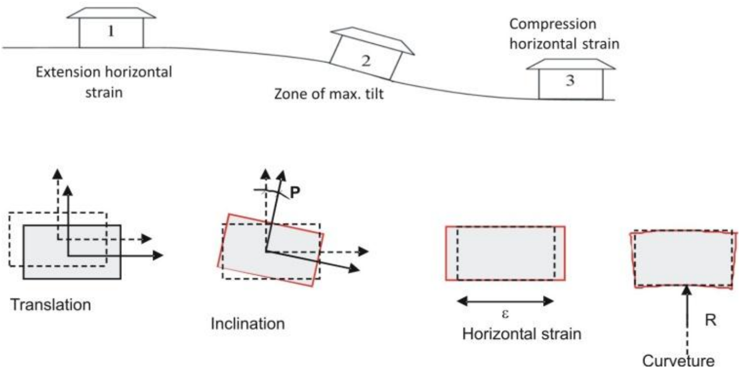

Figure 3: Different types of movement affecting a structure (Deck et al., 2003)

1.3 Mitigation Methods of Subsidence Consequences

The mitigation methods are very important to protect structures from the subsidence effects. The table 1 summarizes the existing methods and can be used up today. The mains methods of the risk management are classified on three categories: i) The reduction of the hazard intensity by reducing the probability of the cavity collapse and the propagation to the surface; ii) The strengthen of the structure by increasing the capacity of the structure to resist against the hazard; iii) The reinforcement of the soil and the foundation to stop the propagation of the collapse to the surface.

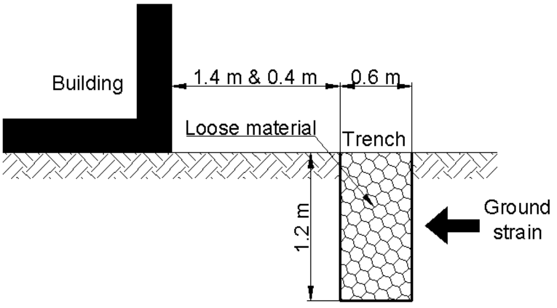

Figure 4: Presentation of peripheral trench technique

Table 1: Mitigation methods to protect buildings against subsidence

	MITIGATION METHOD	NEW	OLD
SOIL	Filling	x	x
	Periphery trench	x	x
	Reinforcement by injection	x	x
	Reinforcement by geotextiles		
FOUNDATION	Improvement the type of foundation	x	
	Horizontal sliding Interfaces between soil and structure	x	
	Adaptation a foundation		x
STRUCTURE	Structure type and function	x	
	Implantation	x	
	Architecture	x	
	Dimensions and conception of the structures	x	
	Using materials	x	
	Vertical interfaces and joints	x	
	Reinforcement of the structure	x	x

We focus the paper on the periphery trench; this method concerns the soil and the foundation types. The raison of this choice is low cost and the application of the method for individual houses. The Periphery trench is a vertical slot realized in the existing soil at a horizontal distance from the structure. The trench is filled with a compressible natural or artificial material. The method is useful for existing and new structures (Peng et al., 1996).

2 STATE OF KNOWLEDGE

Few back analyses exists to demonstrate the efficiency of the method and to give executable recommendations. Many authors (Whittaker and Reddish, 1989; Kratzsch, 1983; Luo et al., 1992; Peng et al., 1996 ; Al Heib, 2008), propose this mitigation method. The following remarks can be listed:

- Different filling material can be used (gravel, coke, peat, etc.), with few data concerning the mechanical proprieties.
- The width of the trench varies between 40 and 60 cm, the distance between the structure and the trench limit is about 2 m and the depth of the trench varies between 60 cm and 1 m.
- The trench is placed under the level of the foundation.

2.1 In-situ Observations

Different research actions were done to evaluate the trench performance. The analyses were based on the in-situ observations and numerical methods (Luo & al. (1992) and Al Heib (2008). Peng et al. (1996) follow the behavior of 12 individual houses to determine the performance of the trench. The houses were under the influence of subsidence induced by a longwall of deep coalmine, the horizontal strain varies between 5 mm/m and 15 mm/m. The trench was around three house borders; the filling material was coke. The trench reduced the tension strain about 35% and 65% for the compression strain. From this experience they recommended a trench with 60 cm width and 60 cm depth.

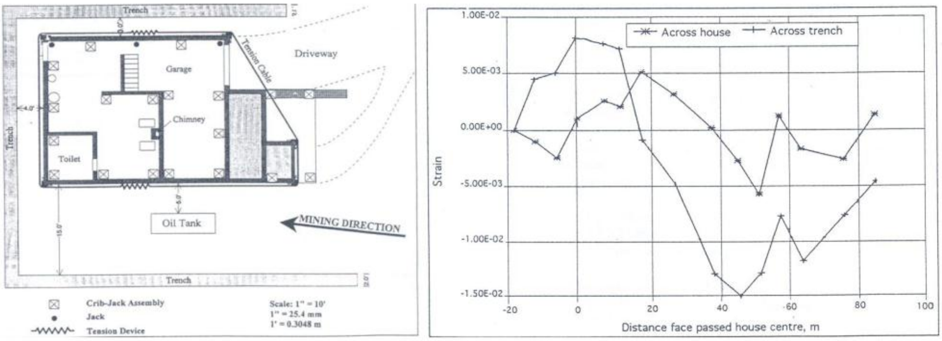

Figure 5: The effect on the trench on the strain from in-situ measurement in USA (Peng et al. 1996)

2.2 Numerical Modeling

Luo et al. (1992) used 2D finite element model to investigate the dimension of the trench. The boundary conditions correspond to a curvature of 5/10-5 l/m and a compression horizontal strain of 0.30 mm/m. The comparison was done between the two configurations with and without the trench allowing determining the contribution of the trench by reducing the horizontal strain. Figure 6 shows the ratio of the reduction of stresses for different parameters of width and depth of the trench. The structure stress decreases with the increasing of both depth and the width of the trench. The ratio becomes less important when the width is equal to 1.2 m and the depth is greater than 0.6 m under the foundation level. Luo & al. conclude that the trench is sufficient with the above values with good efficiency around 60%.

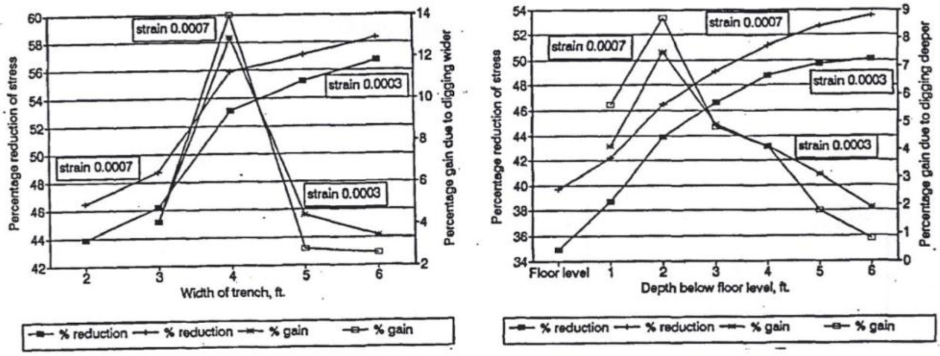

Figure 6: Effect of the trench on stress distribution on the structure function of the width and the depth of the trench Luo & al., 1992)

2.3 Physical Modeling

Hor et al. (2010) used a physical model to study the impact of the trench in subsidence reduction. The building model was positioned in maximum slope zone and in tensile zone. Two distances of 1.4 m and 0.4 m between the trench and the building located in tensile zone were tested, whereas only a distance of 1.4 m was assigned for the building in maximum slope zone. The physical model allows estimating the efficiency of the peripheral trench by either comparing the horizontal strain in the building or the strain of the ground surrounding it under conditions with and without the presence of the trench.

Table 2: Average horizontal strains of building and its surrounding ground

Building's position	Distance between trench & building (m)	Horizontal ground strain (mm/m)		Horizontal building strain (mm/m)		Strain reduction (%)	
		Without trench	With trench	Without trench	With trench	Ground	Build ing
Maximum slope zone	1.4	-2.88	-0.93	-0.20	-0.13	-67.7	-35.0
Tensile zone	1.4	-2.26	-1.79	-0.16	-0.07	-20.8	-56.3
	0.4	-	-	-0.16	-0.10	-	-37.5

For structure located in maximum slope zone, the average compressive strains in Table 2 shows a reduction of almost 70% of the horizontal strain of the ground surrounding the building in the case with trench compared to the case without trench. On the other hand, the reduction is equal to 35% if building strains are considered. For structure in tensile zone, the trench diminishes about 21 % of the surrounding ground strain. Around 56% and 38% of strain reduction are found for buildings with trenches respectively at 1.4 m and 0.4 m distance. From the obtained results, we can provide the following judgments:

- The efficiency of the trench depends on the position of the building. In terms of ground strain, the trench is much more effective for the maximum slope position; while it is less effective, regarding to the building strain.
- The closer the distance between the building and the trench, the less effective is the peripheral trench.

3 CHARACTERIZATION OF FILLING MATERIALS

The contribution of this study is to confirm the role of the trench for different ground strain, in the presence of a masonry structure. We developed a soil and structure model with the presence of the periphery trench. The considered structure is a masonry wall in 2D. The distinct element method allows taking into account the interface between soil and structure, and the interface between the different structure elements. One soil layer is modeled 50 m wide and 15 m high. The boundary conditions correspond to a horizontal strain compression (Figure 7).

The soil corresponds to isotropic and homogenous material and is characterized by linear elastic-perfectl plastic behavior with Mohr-Coulomb criterion. The masonry wall behavior is elastic, an interface was simulated between the structure and the soil, the interface facilitates the tangential displacement when the soil is loaded by the subsidence and compression strain. The wall is stiffer than the soil. The trench width is 50 cm and the depth is 1 m. It is placed 1 m from the structure limit and the trench is first considered as empty. The boundary conditions are no vertical displacements at the bottom and the two vertical boundaries are subjected to horizontal displacements.

Figure 7-b presents two case studies corresponding to 6 mm/m and 12 mm/m. The trench contributes to the decreasing of the soil deformation. The following remarks can be done: the deformation of soil and the structure are smaller than the applied deformation on the boundaries, the reason is the presence of a rigid masonry structure, and the trench reduces the soil strain by about 45%. Whatever, the trench increases slightl the strain of the base of the structure.

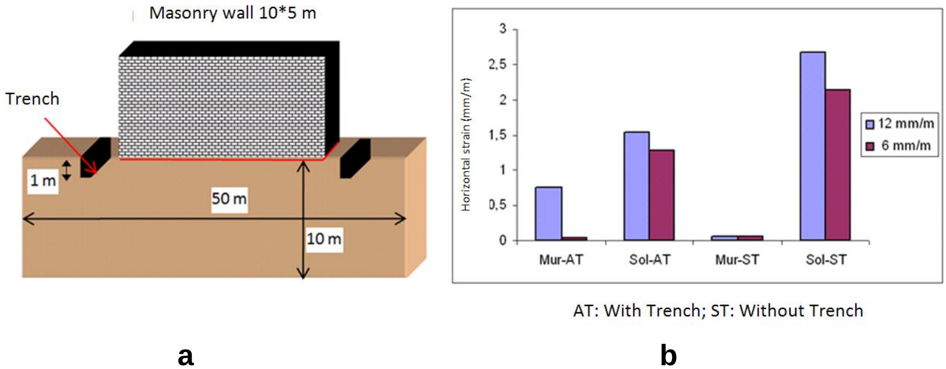

Figure 7: 2D Numerical model (a) to study the effect of trench on soil and structure and Horizontal strain for different configurations (b)

The second numerical model concerns a 3D numerical model using finite elements code. We studied different values of Young Modulus of filling material for the trench. The geometry of the model is presented on the Figure 8. The model corresponds to a thickness of the soil layer equal to 20 m. The structure corresponding to a slab is located in the maximum tilt zone and the distance between the structure and the trench is equal to 1.4 m. The dimensions of the trench are 0.6 m in width and 1.2 m in depth.

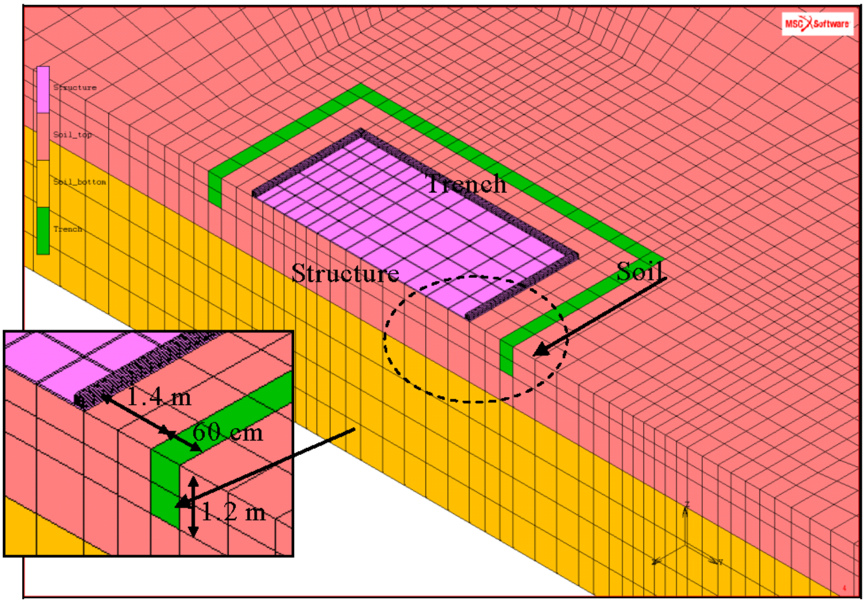

Figure 8: 3D numerical model with different values of filling material

The effect of the ratio on E_{tp}/E_s is studied by increasing the value of the Young modulus of the trench E_{tp}. The ratio E_{tp}/E_s varies between 1 and 30%. These configurations were compared to the configuration without trench. An example of the influence of the trench is illustrated in Figure 9 for E_{tp}/E_s=10%. The influence of the trench on the horizontal strain is obvious. One can observe that trench modifies and form a barrier against the propagation of the horizontal strain.

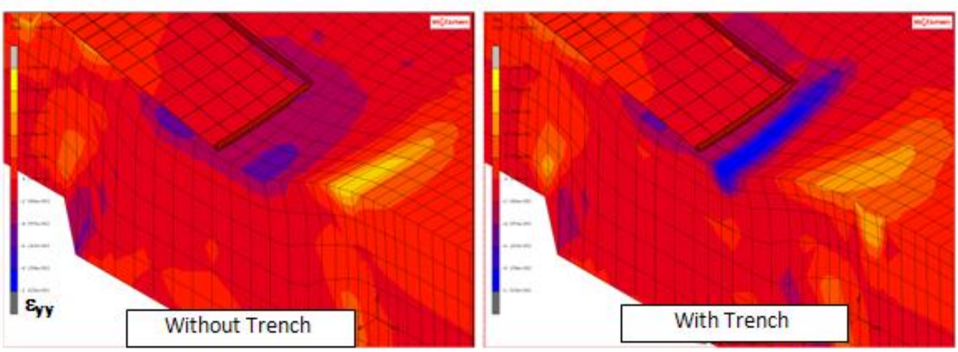

Figure 9: Horizontal strain distribution with and without the trench

Table 3 and figure 10 present the maximal horizontal strains of the soil, the trench and the structure for different values of E_{tp}/E_s. The relation between the reduction of the deformation and the ratio E_{tp}/E_s is non linear. For ratios E_{tp}/E_s between 1% and 10%, a positive impact on the reduction of soil and structure strains is observed. Whatever, when the ratio is more important, the impact is negligible and the trench is not very efficient. When the ratio E_{tp}/E_s =1%, which correspond to very compressible material, the reduction of the horizontal strain is 80%.

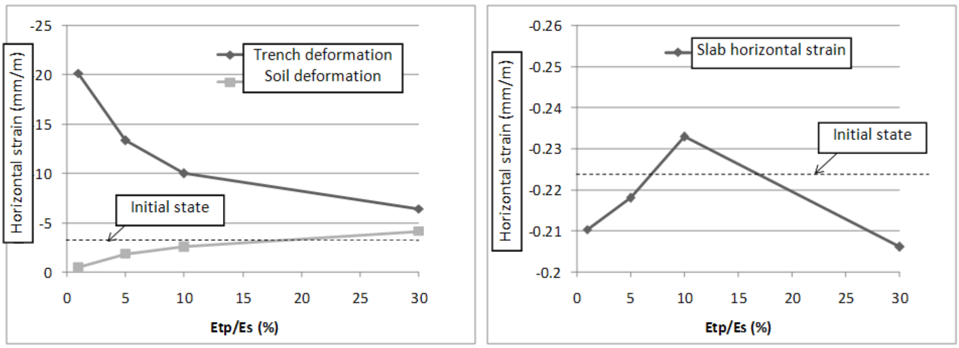

Figure 10: Effect of the trench on horizontal strain function of the ratio of soil and trench Young modulus

Table 3: Strain reduction (%) at function of E_{tp}/E_s ratio

Parameter	Trench efficient indicator			
	E_{tp}/E_s=30%	E_{tp}/E_s =10%	E_{tp}/E_s =5%	E_{tp}/E_s =1%
ε_{hmax} (soil)	-	-16%	-39%	-83%
ε_{hmoy} (structure)	-8%	-	-2%	-6%

4 CONCLUSION

The physical and numerical modeling approaches were carried out to study the behaviour of a mitigation technique – i.e. peripheral trench - used to reduce the damage to buildings due to ground movements. The trench described in this paper has proved very effective in reducing the compressive strain in the ground and also in the building. Its efficiency varies depending on the building location relatively to the subsidence trough, and on the distance from the building. The obtained results are interesting since they are comparable with those from observations and numerical modeling. The trench is efficient when the filling material is very compressible, its Young modulus must be less than 10% of that of the soil. The reduction of the horizontal strain of the soil may decrease the damage of structures located on the subsidence influence zone.

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