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Interaction between the Existing and the New Constructed Tunnels

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ABSTRACT

The effect of construction new tunnel on nearby tunnel was investigated using finite element software program SIGMA/W. Two methods of excavation were used, one using one stage in construction of tunnels and the other using eight stages of excavation. The analysis also carried out to study the effect of nearby tunnel on existing tunnel by varying the pillar width (W), using W equal to 3, 5, 7 and 12 m. The results show that, using stages in construction of tunnel has no significant effect comparing with one stage. The study indicates that there is significant effect of position of new tunnel on the existing tunnel.

Keywords: Tunnel, Excavation Stages, Nearby Tunnel.

التداخل بين النفق الموجود والانفاق الحديثة الانشاء

الخلاصة

تم دراسة تأثير انشاء نفق جديد على نفق موجود باستخدام طريقة العناصر المحددة وباستخدام برنامج سكما (SIGMA/ W) لقد تم استخدام طريقتين للحفر اولا الحفر بمرحلة واحدة والطريقة الاخرى با استخدام ثمانية مراحل للحفر. كما تم دراسة تأثير موقع النفق الجديد عن النفق القديم من خلال تغير (w) (هي المسافة بين حافة النفق القديم والنفق الجديد) حيث تم استخدام اربع قيم وهي 3, 5, 7 و12 متر . ان النتائج اظهرت عدم وجود اي تاثير من استخدام مراحل متعددة للحفر مقارنة مع مرحلة واحدة . والدراسة اعطت مؤشر بانه موقع النفق الجديد له تأثير كبير على النفق القديم.

INTRODUCTION

In urban areas, the use of tunnels has been increased considerably. The state of stress and the displacement in a soil around a tunnel will be changed by the construction of a new tunnel. The influenced area depends on the type, properties of subsoil, insitu stress, tunnel depth, size and supporting system.

Construction of a new tunnel nearby existing tunnel may affect the performance of the existing tunnel; therefore, it is necessary to understand the interaction mechanism between tunnels due to the construction of new tunnel.

The objective of this research is to investigate the behavior of an existing tunnel due to construction of new nearby tunnels focusing on the method of excavation and on the distance between existing tunnels (Pillar width W).

PREVIOUS STUDIES

Interaction between closely spaced tunnels has been studied using a variety of approaches such as experiment, analytical, numerical.

Fotieva and Sheini [1] used analytical studies of the twin tunnel; the study was based on the assumption of an elastic soil and using a Laplace Transformation technique. The analysis was applied to an example of a lined tunnel of 6 m diameter at depth of 36 m. The soil and liner were assigned material properties of rock and concrete, respectively. A second tunnel of the same diameter was excavated adjacent to the existing tunnel at a central distance of 8 m which gives a pillar width w to tunnel diameter D ratio of W/D= 0.33 . The driving of the second tunnel caus additional causes an stresses in the liner of in existing tunnel led to a maximum thrust coefficient of ($T/\gamma HR^{2}$=0.0053) where H and R, are depth and radius of tunnel, respectively.

Peck et al. [2] discussed the problem of two parallel tunnels of different diameters. A semi-empirical approach was used to develop some general guidelines for the liner distortion that occur due to the construction of a new nearby tunnel. They suggested that when the tunnel spacing is greater than about 2D, where D is diameter of larger tunnel, displacement interaction effects may be neglected.

Two-dimensional finite element studies of this problem are described by Peri [3] and Kanzk et al. [4]. In these cases, it was noted however that three dimensional finite element methods was required to model important features such as driving sequences and rate, changes in initial ground stresses and stiffness and type of excavation and lining but using three dimensions is very costly.

Addenbrooke and Potts [5] used a two dimensional finite elements of twin-tunnel problem using small strain non-linear soil model. They concluded that the interaction between two tunnels passing at depth depends on relative tunnel position (side by side or vertically above) and on spacing.

Saleem and Gell [6] studied the interaction between new tunnels which is about 7 m from water transmission tunnel with a diameter of 4.8 m which serving for water supply of the city of Munich since 1983 without any problem. As the two parallel tubes of the highway tunnels (width 12 m, height 8.5 m) are running in a distance of 40 m the existing tunnel is crossed twice. The highway tunnels and the existing tunnel do not intersect perpendicularly therefore these crossings are located in a distance of 56 m. The increase of compression stresses around the water tunnel due to stress transfer around the highway tunnel was the main item to be investigated.

Some preliminary investigations revealed that the investigation could be reduced to 5 different geometric relations between existing tunnel and new tunnel as shown in Figure

(1) were proposed. Finite Element was adopted using plain strain conditions. All these models and excavation technique are implemented into the finite element –program Sigma. SIGMA/W (version 5). The FEM-calculations revealed that the stress transfer due to excavation of the highway tunnel affects the circumference of the existing tunnel. The magnitude of this effect depends on the distance between the two underground openings (see case 1 – 5). The investigated cases reveal that when the existing tunnel is within the range of the diverted stresses the additional stresses yield maximum values (see case 3). A bigger vertical distance between the underground openings which could be realized when designing the highway is of little influence.

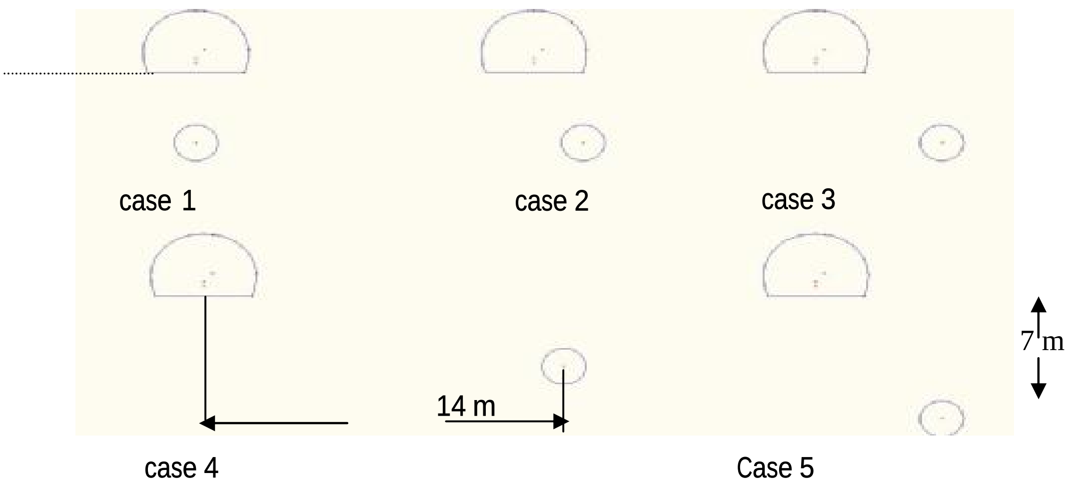

Figure (1) investigated geometric relations (case 1 – 5) between Underground openings.

PRESENT ANALYSES

In this study two-dimensional finite element program using SIGMA/W has been used to predict the behavior of a tunnel under different excavation stages and also to study the effect of construction of new tunnels on existing tunnel. Eight noded plane strain isoparametric elements are used for modeling both the soil skeleton and tunnel liner. The analyses are all performed using linear elastic soil model.

FINITE ELEMENT MODEL

SIGMA/W is a finite element software product that can be used to perform stress and deformation analyses of earth structure. Most common application of the program is to compute deformation caused by earth works such as foundation, embankment, excavation and tunnels. In present paper SIGMA/W used for tunneling as the radius can be given and the exact position of the center of the opening can be specified. Boundary condition can be specified at any node. Also the program can use a ring of elements around the opening; this can be useful to simulate the presence of a liner.

APPLICATION

Construction of new tunnel may lead to unacceptable distortions in the existing tunnel. The nature of the interaction between tunnels depends on the tunnel spacing, size of both tunnels and liner stiffness.

In the present analysis, the old tunnel is circular in cross-section with 6 m outer diameter and 0.45 m of concrete lining thickness. The geological section for a specified position with tunnel axis at a depth is indicated in Figure (2). The finite element mesh is shown in Figure (3). The material properties are shown in Table (1). In this paper, it is required to study the temporary effect of excavation of new tunnels of 6 m outer diameter on the existing tunnel, therefore during this stage; the final concrete lining is not simulated.

MODELING THE TUNNELS

The following modeling procedures are used for the construction of each tunnel in the analyses:

General:

Step 1: Applying initial stresses to the soil with excavated old tunnel. This will be used as initial state of the problem.

Step 2: Starting to excavate of tunnel one

Two types of excavation procedures are used, these are as follows:

1- Excavation of tunnels using one stage
2- Excavation of tunnels using more than one stages
   i)-excavating tunnel one (using 4 stages)
   ii)-excavating tunnel two (using 4 stages)

The program run using 8 stages , stages 1 to 4 are used for tunnel 1 , while stages 5, to 8 are used for tunnel 2.

Figure 3 shows a typical finite element mesh used in these analyses. The following boundary conditions were applied to the model:

i) The base of the finite element model was restrained in both vertical and horizontal direction,
ii) Roller restraints were applied to the side of the finite element mesh.

Three cases are considered, the first case excavating tunnel 1 with pillar width W = 3 m from the old tunnel , the second case move tunnel 1 away from old tunnel to have W = 5 m and the final case move tunnel 1 to have w= 7 m.

The soil parameters adopted in the finite element analysis are given in Table (1). Linear elastic isoparametric concrete elements are used for modeling the old tunnel lining.

Table (1) Properties of the soil profile.

Type of Soil	Modulus of elasticity E (kPa)	Poisson's ratio	Unit weight (Ɣ) kN/m^3
Silty clay	80000	0.333	19.5
Sandy to silty sand	180000	0.263	19.7
Sand	150000	0.284	20.0

GENERAL BEHAVIORS OF THE TUNNELS

The general behavior of the tunnel can be described by the distribution of deformations and stresses resulting from two dimensional finite element analyses. The typical contour lines for vertical deformation of the soil surrounding the tunnel using one stage and eight stages in excavating tunnel 1 and tunnel 2 are given in Figures (4 and 5) respectively. The contour lines of horizontal displacement using one and eight stages are as shown in Figures (6 and 7). The contour lines of vertical stress using one stage and eight stages of excavation are shown in Figures (8 and 9) respectively. The variation of surface settlement along the x-axis is shown clearly in Figure (10) using two methods of excavation.

The surface settlement and sub surface settlement for different types of excavation tunnel are also shown through Figures (11 and 12).

Figure (13) shows the variation of vertical settlement above the crown of existing tunnel using eight stages in excavating tunnel 1.

Figures (14 to 22) show the deformation occurs around existing tunnel due to excavating nearby tunnel 1 at different position with pillar w equal to 3, 5 and 7 m.

EFFECT OF EXCAVATING NEW TUNNELS ON EXISTING TUNNEL

i- Effect of method of excavation:

The method of excavation has no significant effect on the vertical settlement; horizontal displacement, vertical stresses and surface settlement, this is due to the fact that in this analysis the excavation carried out without lining, this is clearly shown through Figures (4) to Figure (10).

ii- Effect of Pillar width (W)

Moving Tunnel one to a new position (W= 5m, 7 m and 12 m) causes a great reduction in the vertical displacement, as clearly shown in Figure (22). This reduction is due to shifting the new tunnel from existing.

Main Conclusions:

Two dimensional finite element analyses have been successfully employed to predict the influence of the construction of new tunnels on the existing tunnel. Using one stage in excavating of tunnel or eight stages has no effect on the final result. A great reduction in vertical displacement is noticed as nearby tunnel moves away from existing tunnel.

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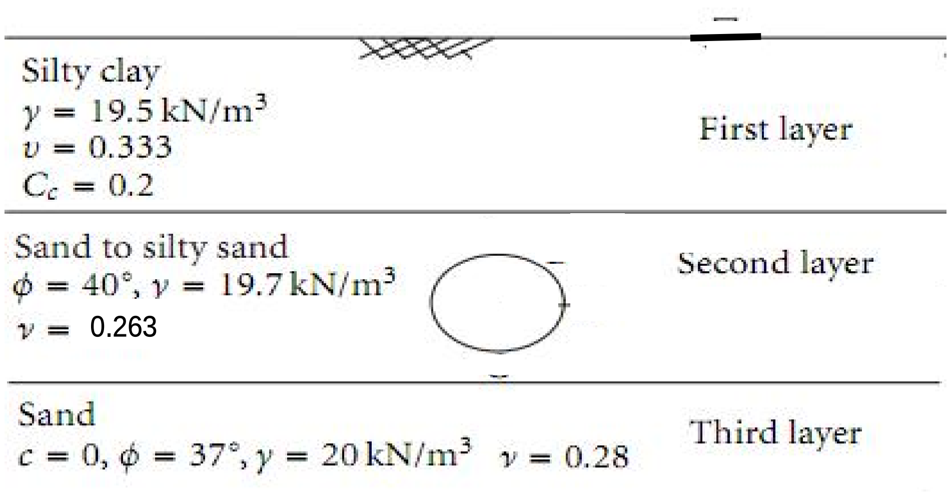

Figure (2) Geological profile and Soil properties adopted Along Baghdad Metro-Line.

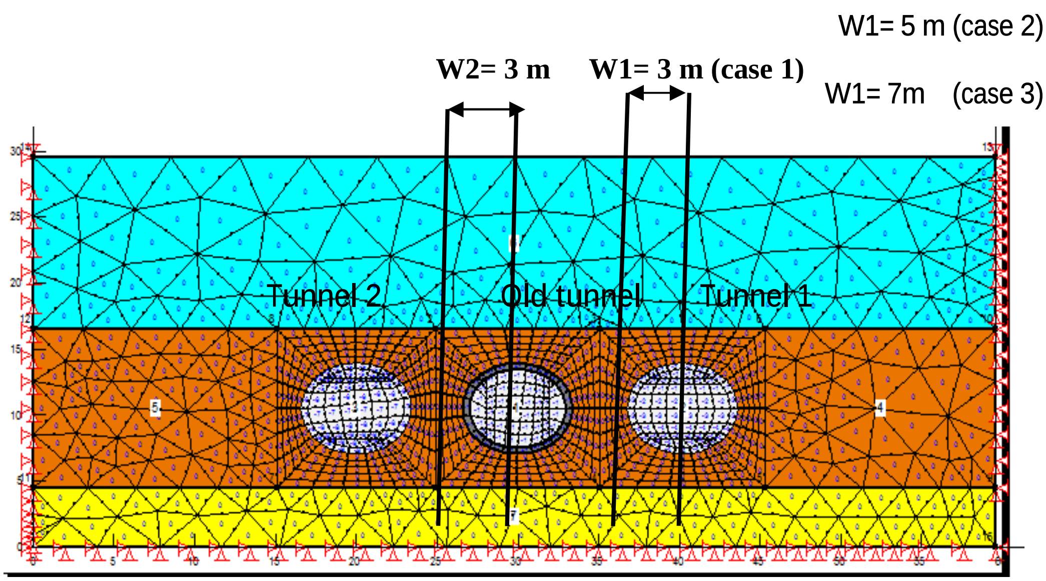

Figure (3) typical finite element mesh of tunnels –soil system.

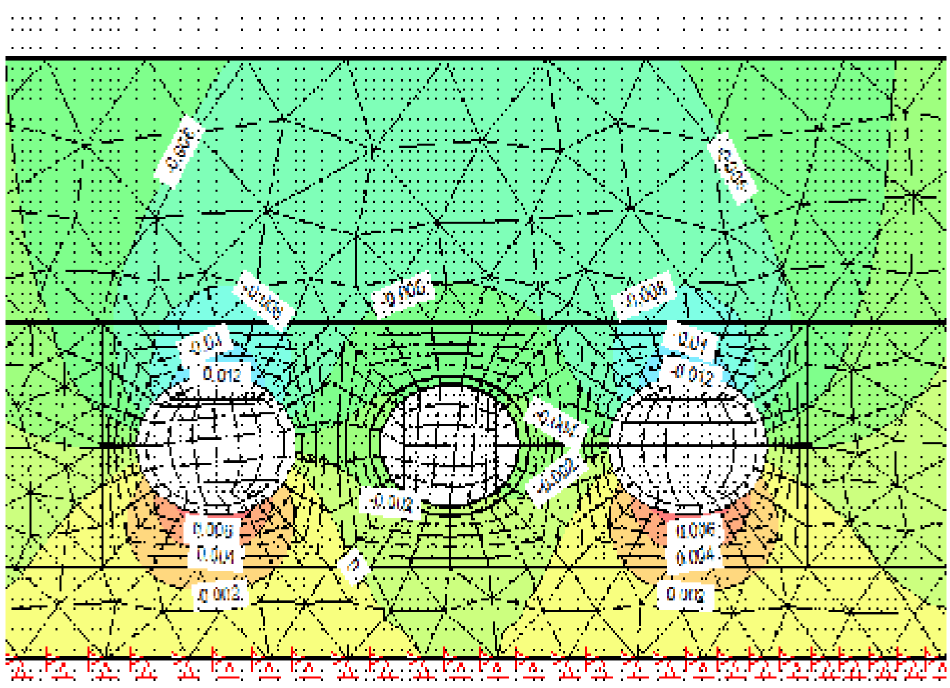

Figure (4) contour lines of vertical displacement using one stage in Excavation process.

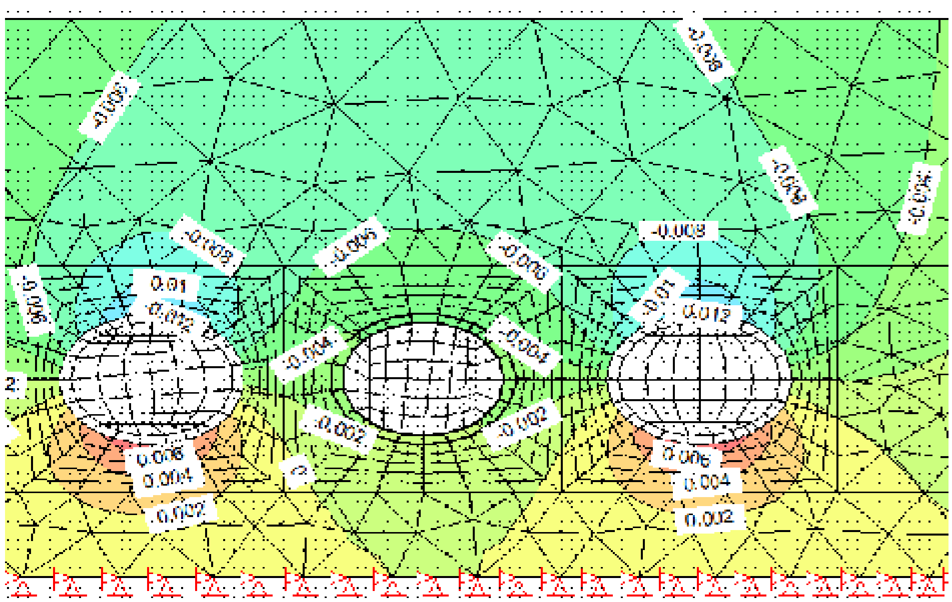

Figure (5) Contours line of vertical displacement using stages in excavation Process

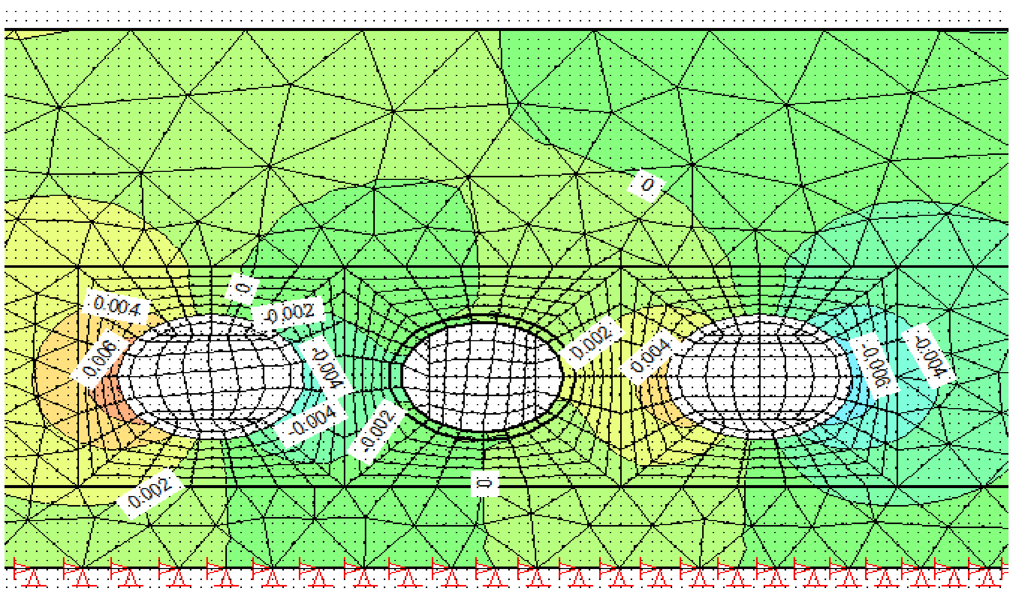

Figure (6) contour lines of horizontal displacement using one stage in Excavation process.

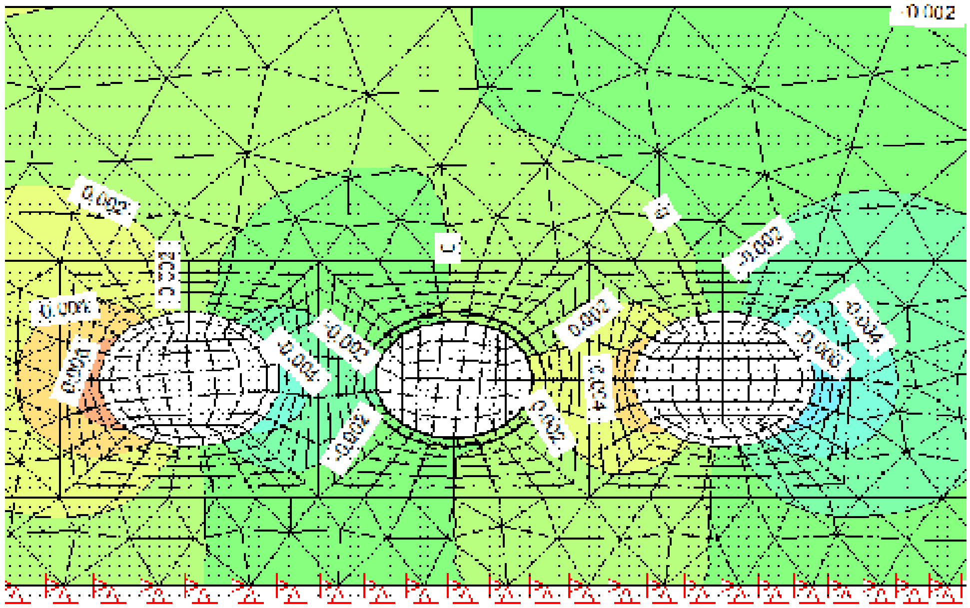

Figure (7) Contour lines of horizontal displacement using eight stages in Excavation Process.

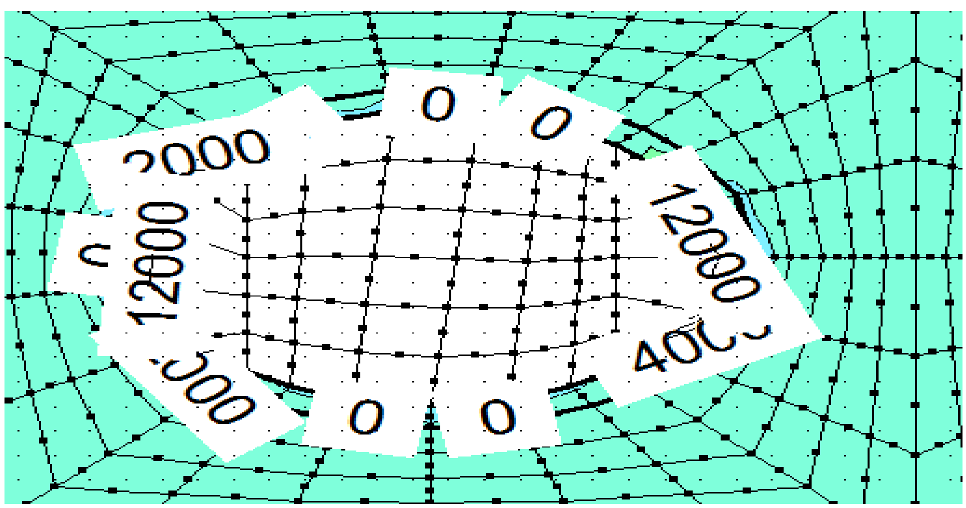

Figure (8) contour lines of total vertical stresses using one stage in Excavation of the tunnel.

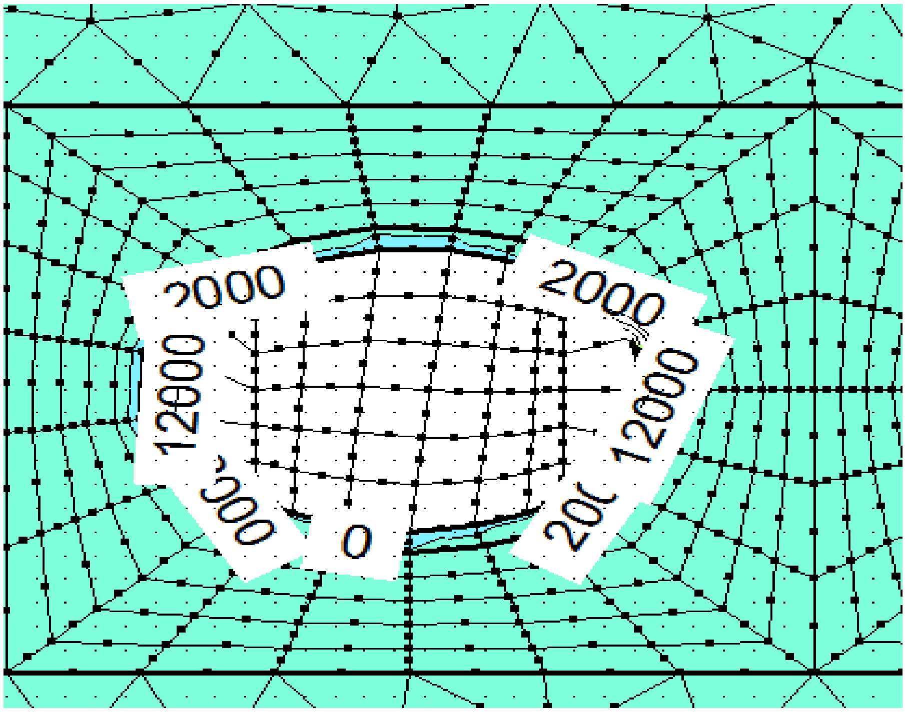

Figure (9) contour lines of vertical stresses using eight Stages in excavatingthe tunnel.

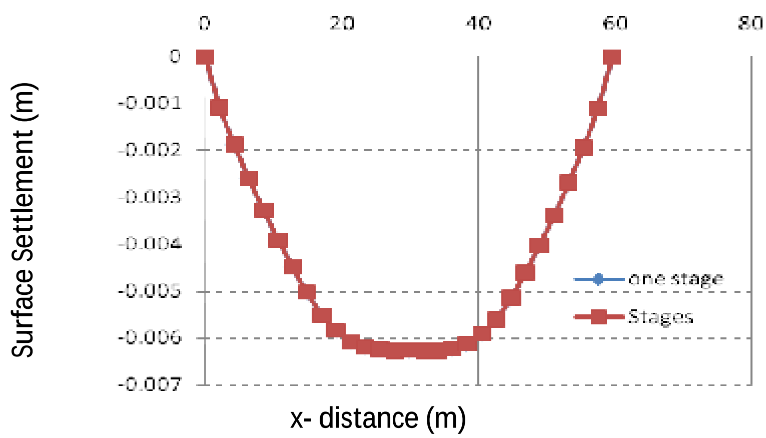

Figure (10) The effect of method of excavation on the surface Settlement due to excavation of tunnel 1 and tunnel 2.

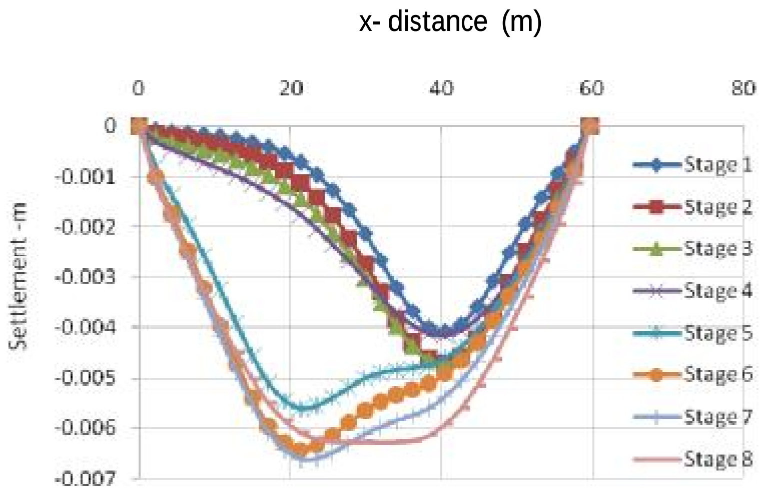

Figure (11) Surface Settlement Due to Excavation of Tunnel 1 and Tunnel 2.

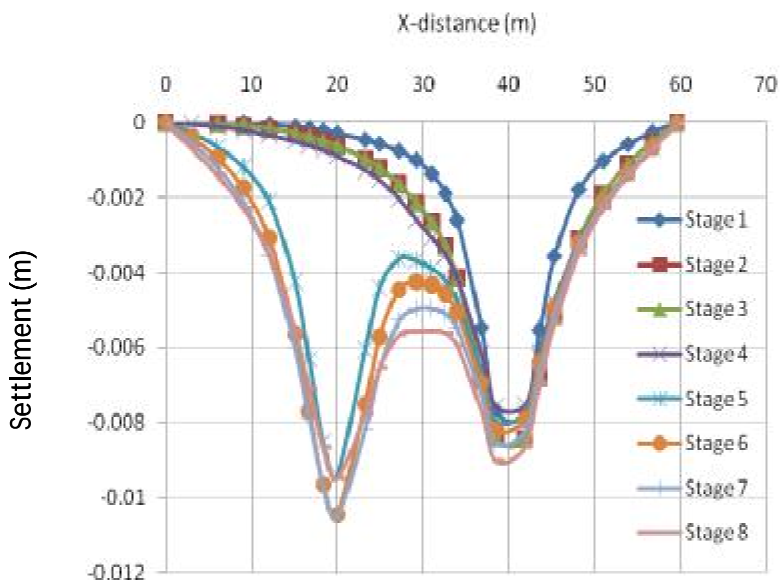

Figure (12) Subsurface Settlement (above the tunnel) due To excavation of tunnel 1 and tunnel 2.

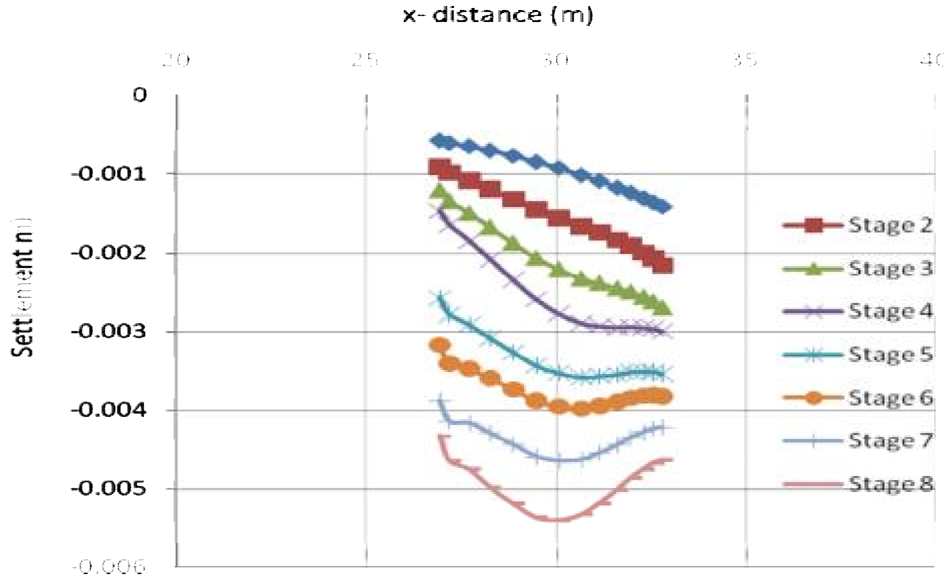

Figure (13) vertical Settlement above the crown at each Stages of Excavation.

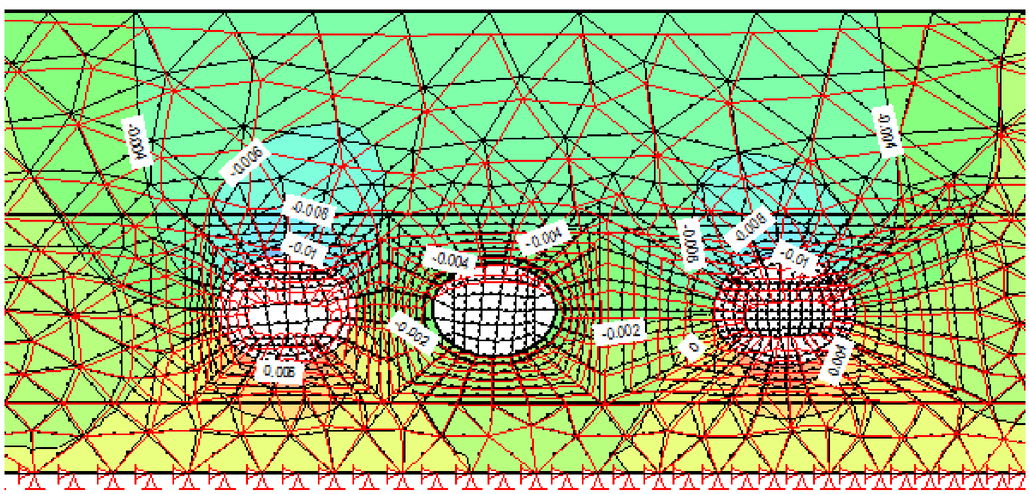

Figure (14) Typical contour lines of vertical deformation after moving tunnel one to a new position with pillar width , W = 7 m from the existing tunnel.

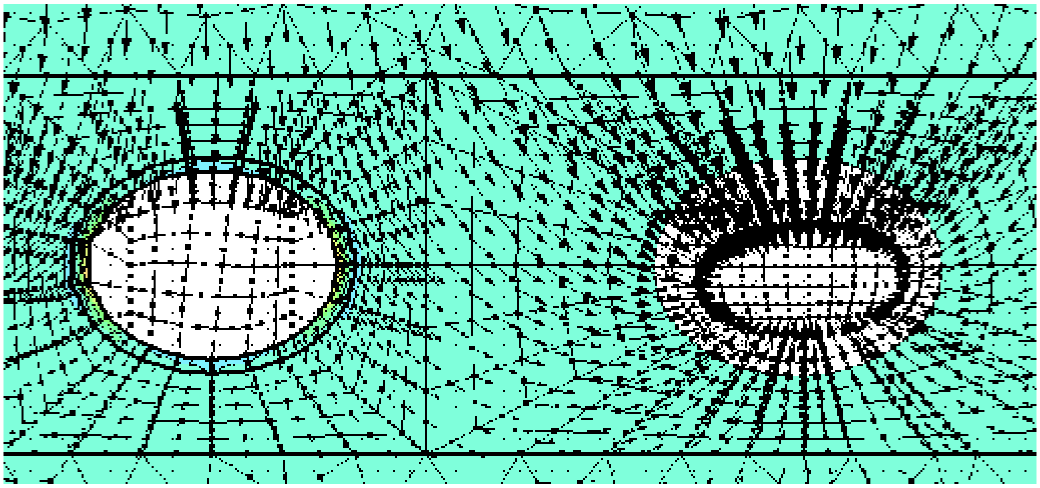

Figure (15) Vectors represent soil movement due to excavation of tunnel one with w= 7 m from the existing tunnel.

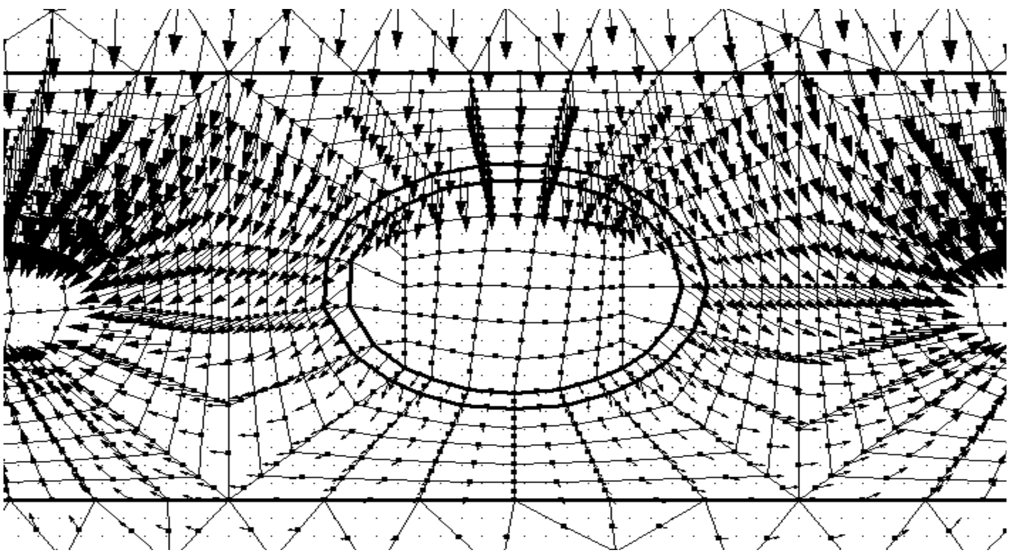

Figure (16) Deformation vector around existing tunnel due to excavation of Tunnels for w= 3m for tunnel 1 and w= 3 m for tunnel 2.

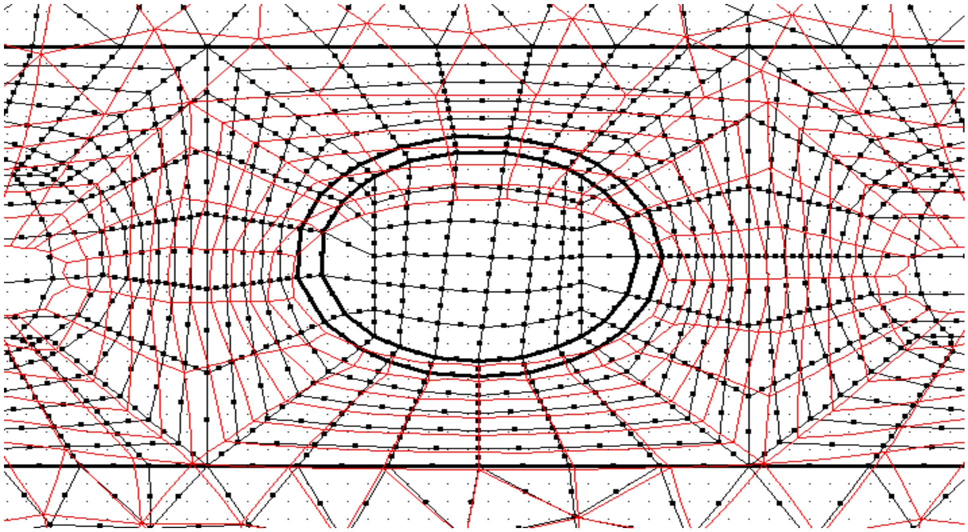

Figure (17) Deformation mesh using W= 3 m for tunnel 1 and w= 3m for tunnel 2.

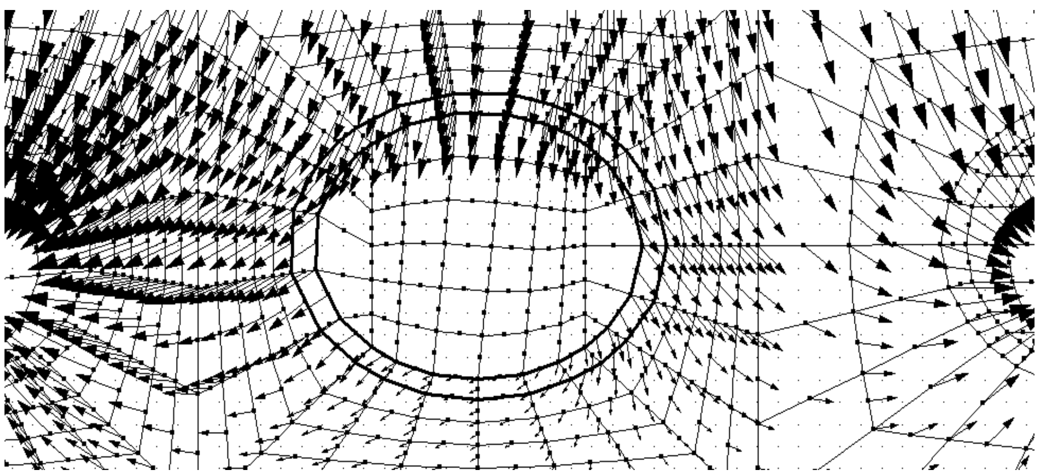

Figure (18) Deformation vector around existing tunnel due to excavation ofTunnels for w= 5m for tunnel 1 and w= 3 m for tunnel 2.

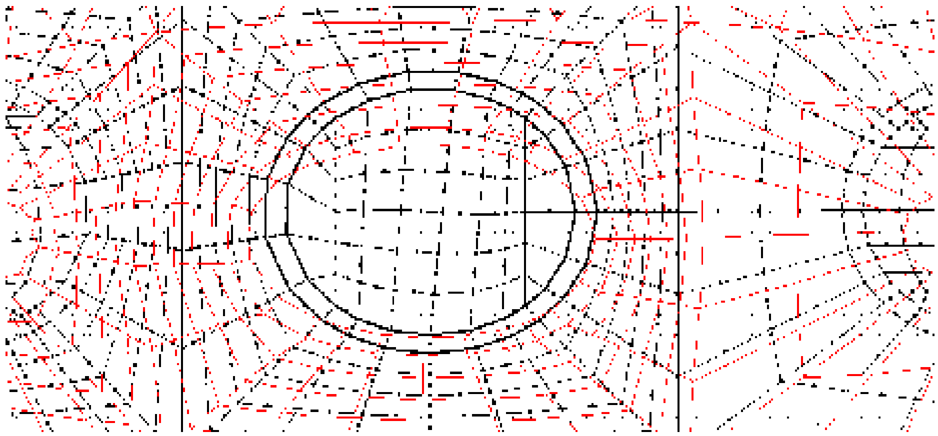

Figure (19) Deformation mesh using W= 5 m for tunnel 1 and w= 3m for tunnel 2.

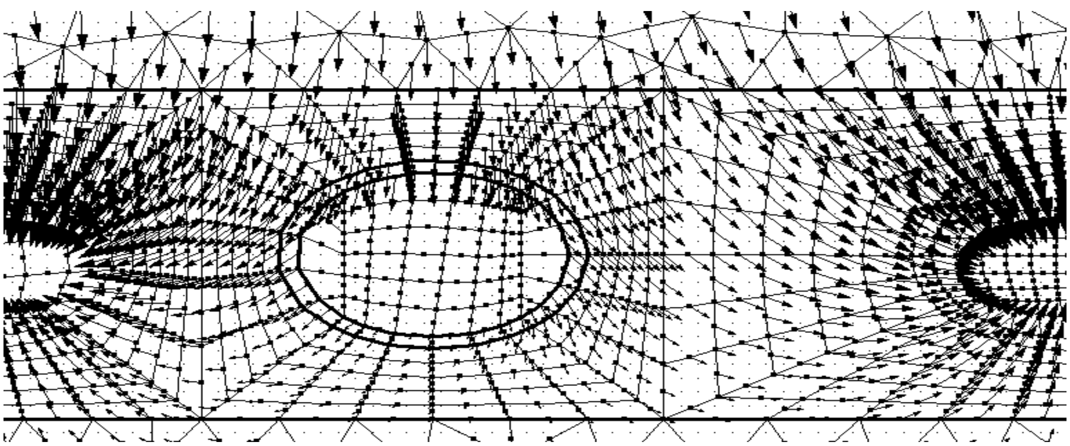

Figure (20) Deformation vector around existing tunnel due to excavation of tunnelsusing w= 7 m for tunnel 1 and w= 3 m for tunnel 2.

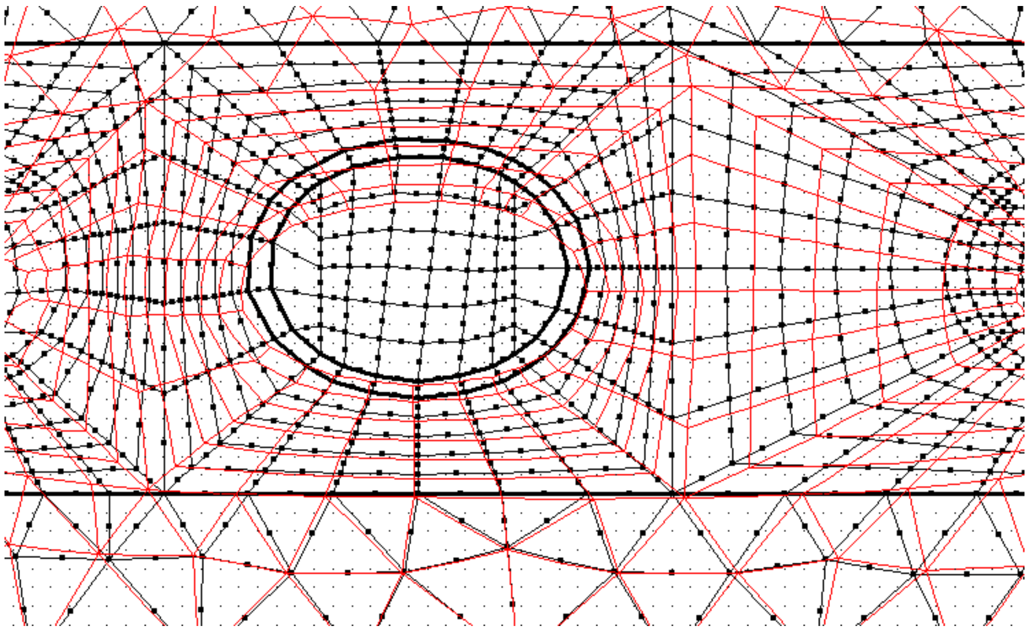

Figure (21) Deformation mesh using W= 7 m for tunnel 1 and w= 3m for tunnel 2.

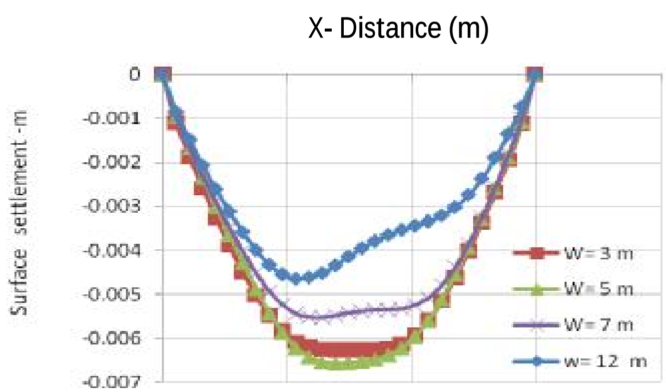

Figure (22) Surface settlement due to excavation of tunnel 1 atDifferent pillar width W= 3, 5, 7 and 12m.