Methods of increasing fatigue life and reducing runway deflections following an explosion beneath a cement concrete runway

John W. Bull[a,*], C.H. Woodford[b]

[a]School of Civil Engineering and Geosciences, [b]Information Systems and Services, University of Newcastle upon Tyne, Claremont Road, Newcastle upon Tyne NE1 7RU, UK

Abstract

This research considered the effect of an underground explosion on the fatigue life of a cement concrete runway and the supporting subgrade following the formation of a camouflet. For an unpressurized and empty camouflet void, the fatigue life of the runway increased or decreased depending upon the material property sets and depth of detonation. Pressurizing the void reduced runway surface displacements and for two material property sets, increased the subgrade fatigue life. For the unpressurized void, the minimum runaway surface displacements occurred for a filled camouflet void. In the apparently undisturbed subgrade outside the cone of disturbance, the fatigue life reduced for all material property sets.

Keywords: Camouflet; Concrete; Fatigue life; Finite elements; Runway repair; Underground explosion

1. Introduction

Following an explosion and the formation of a camouflet void beneath a cement concrete runway, the military repair team must locate, identify, assess, repair and return the runway to operational conditions within three hours. The research described below allows the team to estimate the fatigue life remaining in the runway before commencing the repair.

Previous research has shown the effect on the runway surface displacements and on the runway's fatigue life of filling the void, increasing the depth of detonation and changes in the Young's modulus of the subgrade due to the explosion [1,2,3,4,5,6]. Aspects of research undertaken since those publications have been presented [7,8].

Reference [7] considered the fatigue life remaining in the runway following an explosion at different depths in the subgrade. Reference [8] considered the effect of pressurizing and partially filling or filling the void.

2. Camouflet description

The detonating of an explosive sufficiently deeply under a runway will produce a camouflet and will effect changes in the Young's modulus of zones 2, 3, 4, 5 and 6 of the subgrade identified in Fig. 1. The void and zones 2, 3, 4, 5 and 6 form the camouflet. Ten material property sets of subgrade Young's moduli for zones 2, 3, 4 and 5 have already been considered [7,8]. Table 1 gives the Young's modulus for zones 1 to 8 inclusive together with the original Young's modulus values for the zones before the detonation. The runway, zones 1 and 8 of Fig. 1, are considered to be unaffected by the detonation.

The research assumed that a 213 kg explosive charge detonated in the subgrade at depths of between 8.35 m and 18.35 m and produced a void with horizontal and vertical diameters of 6.25 m and 6.18 m respectively. A highly compacted shell of subgrade, zones 5 and 6 of Fig. 1 extending to a diameter of 7.55 m surrounded the void. For a detonation depth of 8.35 m, the radii of the interfaces between zones 3 and 4 and zones 2 and 3 were 5.15 m and 6.60 m respectively. The origin of the radii and the point of the cone of disturbance was the detonation point. The interfaces of zones 2 and 3, 3 and 4, and 4 and 5 were spherical and contained within the frustum of the cone. Above the void is the cone of disturbance, within which, due to the detonation waves, the subgrade has been firstly compacted and then loosened with the runway returning to its original level. The base of the cone, on the underside of the runway, had a

* Corresponding author. Tel.: +44 (191) 222 7924; Fax: +44 (191) 222 5322; E-mail: John.bull@ncl.ac.uk

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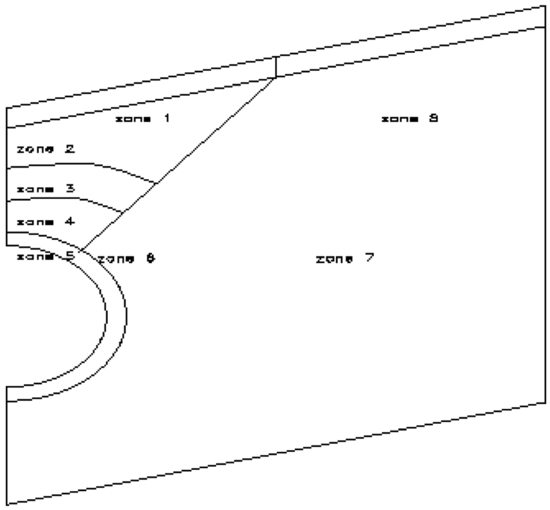

Fig. 1. A slice through the model of the runway, camouflet and subgrade.

diameter of 17.62 m. For detonations beyond a depth of 8.35 m, the thickness of zones 2, 3 and 4 increased each by one third of the increase in the depth of detonation.

The research assumed that the subgrade was elastic, homogeneous and isotropic before detonation. Notwithstanding the non-linearity of the runway and of the subgrade, the ability to carry out linear elastic analysis has proved most useful in developing runway design methods [9]. The research used linear elastic analysis, with nonlinearity being included in the fatigue relationships [10]. The subgrade Young's moduli were calculated using the equation E = 10CBR MPa, which related the subgrade CBR (in %) to a Young's modulus. Zones 1 and 8 represented pavement quality concrete with a Young's modulus of 36,000 GPa. The Poisson's ratio for the subgrade and the concrete were 0.3 and 0.2 respectively.

3. Finite element analysis

The research used PAFEC-FE software to model the camouflet and perform the analysis [11]. Although more sophisticated stress analysis packages were available, the authors preferred to work with software where they had access to the underlying code. Data for the camouflet model was input using the PAFEC Interactive Graphic System (PIGS) interface. A sphere within a cylinder modeled the camouflet and the surrounding material.

Setting the radius and the length of the cylinder to be twice the radius and the depth of the spherical cavity below ground level, respectively modeled the notionally infinite nature of the subgrade surrounding the camouflet. The relatively small depth of the runway had implications for the number of elements required in the model. Initially a two-dimensional cross-section corresponding to a filled void was meshed and cross-sections approximating to empty, 25% filled, 50% filled and 75% filled were formed by appropriate deletions. A succession of five rotations about the vertical axis generated the full three-dimensional model with two-dimensional quadrilateral and triangular elements swept into three-dimensional brick and tetrahedral elements respectively. Three dimensional isoparametric finite elements from the PAFEC-FE 37110 series have generally curved faces and are of the 20-node brick shape and 15-node wedge shape required by the model. Figures 2 and 3 show the finite element mesh used for the 25% filled and the 75% filled void respectively. The model used as many as 4,350 elements and 47,750 degrees of freedom, depending upon the depth of detonation.

4. Conclusion

Analysis of the results showed that for six of the ten material property sets of Table 1 and for all depths of detonation the fatigue life of zone 1 either did not

Table 1
Young's modulus [MPa] for the original and the ten material property sets

Zone number	Material property sets										
	Original	1	2	3	4	5	6	7	8	9	10
1	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000
2	95	95	95	95	95	95	95	95	95	95	95
3	95	190	190	95	95	95	95	7	7	7	7
4	95	190	190	190	95	95	95	95	7	7	7
5	95	950	190	950	950	190	95	95	950	95	7
6	95	950	950	950	950	950	950	950	950	950	950
7	95	95	95	95	95	95	95	95	95	95	95
8	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000	36,000

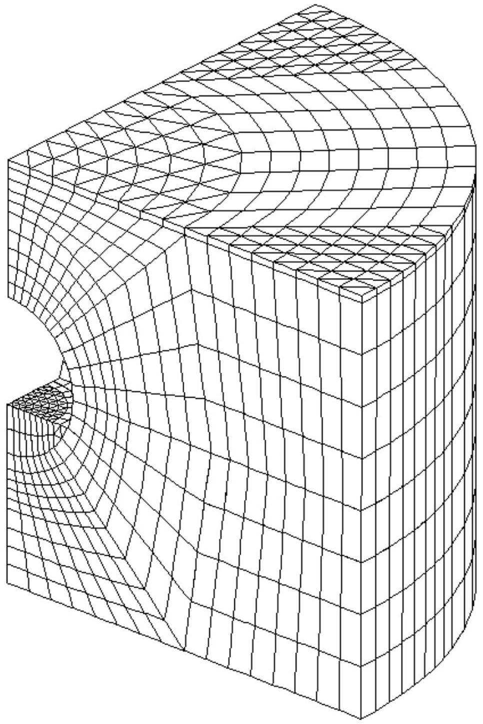

Fig. 2. Finite element model of the 25% filled void, surrounding subgrade and runway.

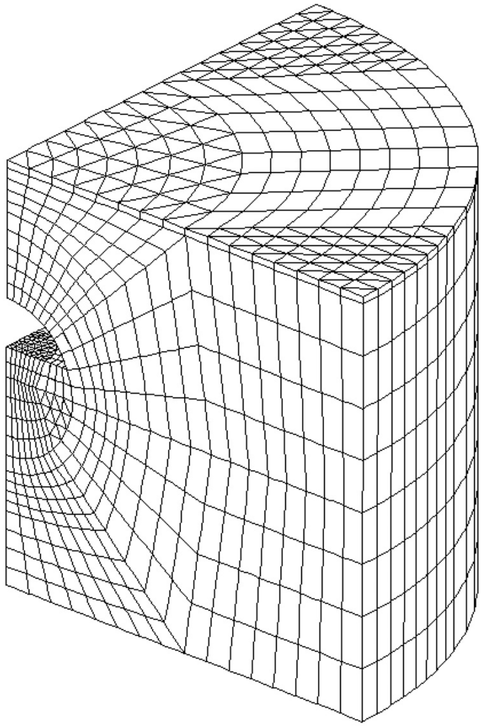

Fig. 3. Finite element model of the 75% filled void, surrounding subgrade and runway.

change or increased. For the four remaining material property sets, the smallest remaining fatigue life occurred for the minimum detonation depth of 8.35 m. As the detonation depth increased so did the fatigue life of zone 1. For zone 8, for six material property sets and all depths of detonation the fatigue life either did not change or was increased. For the four remaining material property sets, the minimum fatigue life occurred for a detonation depth of 10.35 m. For four of the material property sets and for all depths the fatigue life at first reduced as the detonation depth increased but then increased at the maximum detonation depth of 18.35 m [7].

Further research considered the effect of the void being empty, 25% filled, 50% filled, 75% filled or completely filled with subgrade with the void being either unpressurised or pressurised. The results showed that pressurising the void always reduced the runway surface displacements. For the unpressurised void, the minimum runaway surface displacements occurred for a filled void. In only two cases did pressurising the void increase the subgrade fatigue life. In general the 25% filled unpressurised void gave the highest fatigue life, followed by the empty and 50% filled unpressurised void. In the apparently undisturbed subgrade outside the cone of disturbance, fatigue life significantly reduced for all the material property sets [8].

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