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Study of the Mechanical Performance of the Improved Multi-layer Composites under Drop Weight Impact Loads

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Abstract
This study attempts to propose innovative multi-layer cement based composites to have high impact resistance which could be used for runway. In this paper, the performances of two innovative multi-layer composite runway pavements using asphalt concrete-high strength concrete-cement treated aggregate and asphalt concrete-high strength concrete-cement mortar in surface-base-subbase layer were evaluated under impact loads. ABAQUS/Explicit software was used to simulate loading condition and nonlinear stabilized runway pavement layers characteristics. In addition, a detailed parametric study was also carried out to explore the effects of the selected materials and load related parameters in changing the performance of multi-layer composites. The findings of the study will be helpful to introduce protective multi-layer composite runway pavement and consequently to reduce the maintenance work of runway pavement.

Keywords: Multi-layer composites; cement treated aggregate; high strength concrete; mortar; impact resistance; deflection; stress.

1. Introduction
Distress in runway pavement can be triggered due to the impact loads from aircrafts which may be in the form of surface cracking or surface displacement. In addition, accidental incidents of aircraft and even terrorist attack can also develop impact loads which can cause damage to runway pavement surface. Structural degradation of flexible runway pavement due to loads can results in some form of distress such as alligator cracking, corrugation, high severity patch, rutting, shoving etc. in surface layer of runway pavement. Among the mentioned distresses, high severity patch, rutting and shoving appears in the form of downward displacement of localized surface layer of flexible runway pavement. Heavy loads, loads generated due to sudden impact and quality of materials used in the layers of flexible runway pavement has significant contribution in developing such types of localized surface displacement of runway pavement (Federal Aviation Administration’s Technical Report, 2004). The damaged conditions of runway pavement surface layer can impose the requirement of maintenance and rehabilitation of airport runway pavement. The maintenance can be expensive and can cause delays for flight operation in international airports.

In the past few years, numerous research works (Kuo et al., 2004, Yadav and Shukla, 2012, Kim and Buttlar, 2009) were carried out to explore how the impact loads due to hard landing of aircrafts can affect the runway pavement displacement. The structural condition of runway pavements were often determined by researchers by measuring stress, strains, displacement (Buonsanti and Leonardi, 2011, Al-Qadi et al., 2010, Su et al., 2009, Wu, 2012, Ali et al., 2016) and cracking severity (Kim and Buttlar, 2009, Kuo et al., 2004). For instances, Kuo et al., (2004) inferred that the increase in the impact angle increases the surface cracking of runway pavement. Yadav
and Shukla (2012) identified the impact velocity at the runway pavement surface as a crucial factor in increasing the localized surface displacement of runway pavement.

Hence, the issues mentioned above gives a clear indication of the necessity of a protective multi-layer composite runway pavement by introducing effective materials in the layers of runway pavement as the quality of materials can control the displacement of runway pavement (Federal Aviation Administration’s Technical Report, 2004). Hence, the present study attempts to explore effective materials to be used in the multi-layer composite runway pavement layers and consequently proposes new multi-layer composites which are expected to be more protective under impact loads compared to the conventional flexible runway pavement.

The proposed multi-layer composite/ flexible runway pavement is designed following the general mechanism of multi-layer composite structure. The asphalt concrete layer is used in the surface layer to act as the sacrificial layer. Stiff material such as high strength concrete is used in the base layer/core layer to substantially improve the dynamic load resistance. Similarly, bounded cement treated aggregate which is used in the sub-base layer to perform the function of interlayer of a multi-layer composite and to improve the dynamic response of the multi-layer composite/ flexible runway pavement. One of the main reasons for using bound or treated layer is to reduce the thickness of the layer in pavement (O’Flaherty, 2002). Yaghoubi et al. (2013) investigated the influence of layer thickness composed of cement treated aggregate in regulating surface deflection under truck loading and found the effect as significant. Experimental investigations were also carried out to explore some crucial physical and mechanical properties of cement treated aggregates such as early age strength, compressive strength and modulus of elasticity (Lim and Zollinger, 1981, Davis et al., 2007, Guthrie et al., 2005, Xuan et al., 2012).

Current few research works focused on how to design better resistance of reinforced concrete structures and sandwich panels against impact loads (Li et al., 2017; Liu et al., 2019; Gao et al., 2018; Gholipour et al., 2018; Pham and Hao, 2018; Zhang et al., 2019;). The infrastructures especially the runway pavements did not attracted wider attentions. The design of more efficient protective runway pavement against impact loading is still a challenge. Wu and Chew (2014) and Wu et al., (2015) attempted to propose the soft-hard-soft composite system to be used as runway pavement to resist the blast loads, however, its impact resistance is still not clear. However, composite systems that use very high strength concrete or engineered cementitious material and geogrid as reinforcement for asphalt concrete may not be an economic option. It is evident from the literature that apart from what cited above, no other attempt was made in designing runway pavements to perform effectively under impact loads.

This paper proposes two composition of cement-based multi-layer composite/flexible runway pavement and evaluate the performance of the composites under impact loads. The materials used in the proposed runway pavement are easily available, economic and the casting of proposed layers is more convenient compared with the compositions used by other researchers.

In order to evaluate the effectiveness of the materials used in the proposed runway pavement layers and thereby to anticipate the performances of proposed multi-layer composite runway pavements under impact loads, an exhaustive Finite Element (FE) analysis was carried out using ABAQUS/Explicit.

The composition of multi-layer composite runway pavement recommended by Australia is illustrated in Figure 1. The surface layer is composed of dense graded hot mix asphalt (HMA) of 40 mm to 60 mm thickness (White, 2007). However, recently thicker layer of HMA is also suggested following the US standard. The base and sub-base layer usually composed of crushed rock or gravel is used as unbound base or sub-base course. Nevertheless, the practice of cement of lime stabilized base course is also common. The thicknesses of these layers have no definite information and usually varied. The base thickness can be around 150 mm or above and the sub-base thickness can be smaller than the thickness of the base layer (Wardle and Rodway, 2010). All of these layers rest on natural subgrade to disperse the load uniformly.

In the proposed multilayer composite runway pavement analysis, rigid base and stabilized sub-base was used in one model and in another proposed runway pavement, both rigid base and sub-base was used. Impact drop weight tests were carried out on one of new multi-layer composite runway pavement specimen as proposed specimen and Australian standard multi-layer composite runway pavement specimen. The standard thicknesses of all layers were considered same for both multi-layer composite runway pavement models.
The aim of this study, therefore, is to understand the effectiveness of a proposed multi-layer composite runway pavement specimen compared to Australian standard runway pavement specimen through drop weight impact tests. Then to evaluate the performances of two proposed impact resistant multi-layer composite runway pavements under impact loads. A detailed parametric study was also conducted to investigate the effects of a few parameters on the performance of the best multi-layer composite runway pavement under impact loads.

2. Experimental Program

2.1. Specimens and materials

Two multi-layer composite runway pavement specimens were tested by impact drop weight testing machine. One specimen was prepared following the runway pavement section usually constructed in Australia (Wardle and Rodway, 2010) (AC 139-25, 2011).

Fig. 1. Multi-layer composite runway pavement (a) composition (b) application

Fig. 2. Composition of multi-layer composite runway pavement specimens (a) Australian Standard multi-layer composite runway pavement specimen (b) Proposed multi-layer composite runway pavement specimen
Another specimen was prepared with rigid base layer in the multi-layer composite runway pavement specimen. Figure 2 shows detailed dimensions of the specimens and the used materials in the layers of specimens. The material properties including Instantaneous elastic modulus and Poisson’s ratio of asphalt concrete were determined by uniaxial compression test per AS1012.2:2014. Five cylindrical specimens with a dimension at Ø100x200-mm were tested. The loading rate for the compression test was 1 mm/min. The test was conducted at a temperature of 25 degree Celsius. The measured material properties are presented in Table 1.

The Elastic modulus, Poisson’s ratio and compressive strength of cement treated aggregate and high strength concrete was also determined from standard cylinder tests following AS1012.2:2014; Five cylinders were tested and the loading rate was also maintained at 1 mm/min. The tensile strength of cement treated aggregate and concrete was measured per ASTM C1161.

Table 1. Mechanical properties of the materials used in the pavement specimens

| Material                      | Density (Kg/m³) | Elastic modulus (GPa) | Poisson’s ratio | Compressive strength (MPa) | Tensile strength (MPa) |
|-------------------------------|-----------------|-----------------------|----------------|---------------------------|-----------------------|
| Asphalt concrete              | 2200            | 60                    | 0.3            | –                         | –                     |
| Cement treated aggregate      | 2400            | 1.2                   | 0.24           | 20                        | 0.9                   |
| High strength concrete        | 2400            | 38                    | 0.24           | 65                        | 1.9                   |

The loading rate for the flexural test was also 1 mm/min and the load-deflection curve was recorded at the mid-span. The obtained material properties of cement treated aggregate and concrete are also summarised in Table 1.

2.4 Experimental method

The impact tests on multi-layer composite runway pavement specimens were performed by impact drop weight testing machine at University of Wollongong. Figure 3 illustrates the test set-up of specimens and instrumentations. High speed camera was used to measure the vertical deflection at the top surface centre of the specimens. The drop height of impact mass was 3 m and the corresponding impact velocity was 7.7 m/s. The dimension of the rectangular 590 Kg drop mass was 1 m by 0.9 m and an indenter was attached at the bottom of the mass. The height and diameter of the indenter was 70 mm and 100 mm respectively.

![Impact point of indenter-centre of specimen](image)

Fig. 3. Schematic view of drop weight impact test
2.5. Test results

The behaviour of the multi-layer composite runway pavement specimens was recorded by high speed camera for about 10 sec. Later the vertical displacement histories up to the peak deflection before failure of the composite specimens were calculated. Figure 4(a) shows the vertical deflection histories at centre point of the top surface of asphalt concrete for both multi-layer composite runway pavement specimens.

![Deflection histories at top surface centre of composite specimens](image)

Figure 4(a) shows the deflection histories of the Australian standard multi-layer composite runway pavement specimen and the proposed multi-layer composite runway pavement specimen. At the initial stage, the deflection was similar for both multi-layer composite runway pavement specimens. However, with the increase of time, higher deflection was found at Australian standard multi-layer composite specimen compared to the proposed multi-layer composite specimen under impact loading. The maximum deflection under the mentioned impact test condition was found 35 mm and 30 mm for Australian standard runway pavement and proposed runway pavement specimen.

In addition, the damage distributions of Type 1 and Type 2 specimens are illustrated in Figure 4(b) which were found through high speed video camera footage. The asphalt concrete surface layer except the central portion was found to be divided into few segments after the impact from drop mass.

![Failure modes of flexible runway pavement specimens under drop weight impact tests](image)

The central portion of asphalt concrete surface layer which encountered directly the impact load from drop mass was found to be penetrated. The penetration depth varied for Type 1 and Type 2 specimens. The central portion of the base layer for both Type 1 and Type 2 specimens were found to be slightly penetrated. Cracks of significant width were not found in the base and sub-base layers in both Type 1 and Type 2 specimens.
3. Finite element modelling and validation

Finite element (FE) analysis by using ABAQUS/Explicit was performed on the two multi-layer composite runway pavement specimens as discussed in the previous section.

3.1. Element selection and material modelling

The FE analysis considered the asphalt concrete layer, the cement treated aggregate layer and the high strength concrete layer as solid body and 8-node linear brick element with reduced integration and hourglass control (C3D8R) was used to compose the layers. The asphalt concrete was modelled by using Linear Viscoelastic Model through defining Prony series values at 25 degree Celsius. The Prony series data for asphalt concrete at this temperature was adopted from uniaxial compression test data of asphalt concrete cylinders. The cement treated aggregate and high strength concrete was defined as elastic-plastic model and concrete damage plasticity model was used to define these materials. The compressive and tensile strength curves developed during the uniaxial compression test of cylinders and flexure test of beam were used to define these materials. The material properties used in the FE model of two multi-layer composite runway pavement specimens are given in Table 1. The steel impactor was also modelled as solid body and was composed of 8-node linear brick elements (C3D8R) with reduced integration and hourglass control. Standard elastic and plastic properties of steel were provided and overall mesh size was selected as 5 mm.

The mesh size adopted for the asphalt layer, cement treated aggregate layer and high strength concrete layer was 10 mm and by convergence study the mesh size of asphalt concrete at impact region was fixed at 5 mm. The tied-up condition of layers was defined by “Tie” constraint. The strain rate effect was considered as impact load imposes high strain on material and enables the material to take higher stresses compared to the stresses under normal strain condition. In order to find the strain rate in the two types of runway pavement specimen, preliminary FE analysis was conducted on the runway pavement models under specified impact loading. Then dynamic increase factor (DIF) curve was for each material to find the stress and thereby to consider the strain rate effect.

General contact algorithm was used to define the interaction between impactor and the multi-layer composite runway pavement models. The dynamic friction co-efficient was considered as 0.4 at the contact surface of steel impactor and asphalt concrete surface. This because the usual friction co-efficient remain within 0.4-0.55 for these two materials. Pinned support condition was applied at the bottom of the model. Symmetric support condition was provided on two sides of the runway pavement model and the other two sides were not restrained. Two vertical faces of the quarter of drop mass or impactor were also provided symmetric boundary condition. The total surface of the impactor was assigned an impact velocity of 7.7 m/s to simulate the real test condition. The impact velocity was applied by using predefined velocity option available in ABAQUS/Explicit. Figure 5 and Figure 6 gives an overview of the FE models of Australian standard multi-layer composite runway pavement and the proposed multi-layer composite pavement specimen distinctly. The established FE model is
capable to predict deflection and stress. However, it is not capable to show crack propagation throughout the pavement.

Fig. 6. Finite element model of proposed multi-layer composite runway pavement model (a) FE model (b) FE meshing
3.2. Validation of FE model

Vertical deflections at the centre of the top surface of the composite runway pavement models were noted at the end of the FE analysis. Figure 7 and 8 shows the FE result and the Experimental results in terms of deflection history at the top surface centre point for Australian standard multi-layer composite pavement specimen and proposed multi-layer composite pavement specimen, respectively.

Fig. 7. FE and Experimental displacement history for Australian standard multi-layer composite runway pavement specimen

Fig. 8. FE and Experimental displacement history for proposed multi-layer composite runway pavement specimen
Figure 7 and 8 shows the vertical deflection histories at the centre of the top asphalt concrete surface of Australian standard specimen and proposed specimen respectively from impact tests and FE analysis. Both Figures illustrates the similar trend between the test curve and the FE analysis curve. The maximum deflection from the impact test of Australian standard multi-layer composite runway pavement specimen was 35 mm and from FE model of this specimen, the maximum deflection was around 34 mm. The Coefficient of Variation (COV) between the test and FE analysis at the graphical points of Figure 7 is 0.15, 0.1, 0.02 and 0.02. The peak deflection at the top surface centre of proposed specimen was found during the test as 30 mm whereas in the FE analysis, it was around 29 mm. The Coefficient of Variation (COV) between the test and FE analysis at the graphical points of Figure 8 is 0.11, 0.07, 0.03 and 0.02.

Overall a good agreement was found between the results of tests and FE models for the two composite specimens. Therefore, the FE model can be considered as validated model under the test condition.

4. Performance of multi-layer composite runway pavements under impact loads

FE study was carried out on the proposed multi-layer composite runway pavement (Type-1) mentioned in the previous section using FE model in ABAQUS/6.13-3 to predict the performance under impact load of aircraft. The area of the composite runway pavement model was selected as 20 m by 15 m since the change in maximum deflection remains exactly same for larger areas beyond it. In this large scale runway pavement FE model, similar thicknesses of the pavement layers were considered as selected for the impact drop weight test specimen. The depth of the subgrade layer was selected as 2 m (Wu et al., 2014). Figure 9 illustrates the proposed (Type 1) multi-layer composite runway pavement with subgrade, respectively.

The element selection and material modelling of composite model was conducted as described in the previous section for the validation procedure. The material properties of asphalt concrete were adopted from Modarres and Shabani (2015). The element selection and material modelling of subgrade was carried out following Ali et al. (2016). Coarse mesh was selected for all part instances of this large scale multi-layer composite runway pavement model apart from the asphalt concrete surface layer to reduce the computation time.
The mesh size for subgrade layer was selected as 500 mm and 250 mm mesh was considered for the high strength concrete layer. The mesh size in the asphalt concrete layer was selected as 100 mm and in the loading zone of asphalt concrete surface, 50 mm mesh size was found appropriate after performing mesh convergence study. Figure 10 shows the FE meshing of the innovative multi-layer composite runway pavement. Figure 11 illustrates the FE mesh convergence study results.

Loading from wing four wheels of Airbus 380 which deliver the initial impact load was applied over the top asphalt concrete surface. The areas of the rectangles (0.6 m by 0.4 m) (shown in Figure 9) were subjected to impact load of Airbus 380 aircraft as uniformly distributed pressure of 1453 kPa. The contact area of wheel tire and top asphalt concrete surface was calculated following Huang (1993).

\[ A_c = \frac{P}{p} \]

Where, \( P \) is the wheel load and \( p \) is the tire pressure of Airbus 380 aircraft. The weight of the fully loaded aircraft is 2789600 Kg and the tire pressure is 1.3 MPa. The dimension of the tire contact area and load of the aircraft wheel while impacting the runway was calculated following the acceleration graph given by Leonardi (2014). The impulse curve mentioned in Park et al. (2009) was adopted to define the amplitude of impact load. The sides and bottom of the multi-layer composite runway pavement was provided with pinned support and fixed support, respectively.
4.1 Deflection contours of proposed multi-layer composite runway pavement under single impact

Performance of innovative multi-layer composite runway pavements was noted in terms of vertical deflection. Figure 12 shows the deflection contours of top surface of asphalt concrete layer for the innovative runway pavement system described in the previous section.

![Deflection contours for proposed multi-layer composite (Type 1) runway pavement](image)

Fig. 12. Deflection contours for proposed multi-layer composite (Type 1) runway pavement

The deflection contours reveals that the maximum deflection occurred at wheel loading zone and also at the spacing between the two wheels. However, the whole area between the wheel spacing did not undergo to maximum deflection. The peak vertical deflection was found as 1.125 mm and the deflection next to it was around 1.014 mm. This deflection (1.014 mm) was found within the gap region of the dual wheels. Negligible deflections were found at out of the wheel areas.

Another multi-layer composite runway pavement (Type 2) was proposed where the sub-base of the runway pavement was composed of cement mortar instead of cement treated aggregate. Figure 13 gives an overview of the runway pavement composition.

![Composition of proposed multi-layer composite (Type 2) runway pavement](image)

Fig. 13. Composition of proposed multi-layer composite (Type 2) runway pavement

FE model of the this large scale multi-layer composite runway pavement (Figure 13) was analysed under the identical condition described in previous section. Figure 14 shows deflection contours for the multi-layer composite (Type 2) runway pavement.
Deflection contours for the innovative runway pavement (Type 2) show a maximum deflection around 1.101 mm, which is 2.5% lower than the deflection found for the proposed multi-layer composite (Type 1) pavement with cement treated aggregate sub-base. Nevertheless, the maximum deflection was found in a much smaller region for the proposed multi-layer composite runway pavement with cement mortar sub-base (Type 2) compared to cement treated aggregate sub-base (Type 1). Therefore, to reduce the area of damage, the multi-layer composite runway pavement with cement mortar sub-base (Type 2) can be beneficial.

### 4.2 Deflection contours of proposed multi-layer composite runway pavements under repetitive impacts

The performances of the proposed multi-layer composite runway pavements were further analysed under multiple impact from Airbus 380 aircraft. Figure 15 shows the deflection contours at the top surface of innovative multi-layer composite runway pavement for 100 impacts from aircraft.

The maximum deflection was found as 1.425 mm for 100 impacts from aircraft which was 22% higher than the top surface deflection occurred during first impact. The contours also show that the larger areas between the dual wheels of the aircraft undergoes to maximum deflection with the increase of the numbers of impact. Figure 16 shows the deflection contours at top asphalt concrete surface for the proposed multi-layer composite (Type 2) runway pavement after 100 impacts of aircrafts. The maximum deflection for 100 impacts of aircrafts was found as 1.163 mm which was only 5% higher than the deflection for single impact of aircraft. The results of 100
impacts of aircrafts revealed that 19% lower deflection occurred for Type 2 multi-layer composite runway pavement compared to Type 1 multi-layer composite runway pavement. The area under maximum deflection was nearly similar for both types of proposed runway pavements.

![Deflection contours of innovative runway pavement (Type 2) after multiple impacts of aircraft](image1.jpg)

**Fig. 16.** Deflection contours of innovative runway pavement (Type 2) after multiple impacts of aircraft

### 4.3 Stress contours of proposed multi-layer composite runway pavements under single impact

Performances of multi-layer composite runway pavements were also predicted in terms of stress contours. Figure 17 shows the stress contours of top surface of asphalt concrete layer for the proposed Type 1 runway pavement.

![Stress contours for proposed multi-layer composite (Type 1) runway pavement](image2.jpg)

**Fig. 17.** Stress contours for proposed multi-layer composite (Type 1) runway pavement

The stress contours illustrate that the maximum stress occurs over a quite small region which was around 4706 kPa. The stress at load region was 2745 kPa which about 42% of the maximum stress. Negligible stress was found at moderately away locations from the loading areas of wheels of aircraft.

Stress contours (Figure 18) for the proposed multi-layer composite (Type 2) runway pavement shows that the maximum stress was 1517 kPa which was almost 68% lower to the maximum stress found for proposed multi-layer composite (Type 1). The stress at the loading area was 885 kPa for Type 2 runway pavement which was also 68% lower compared to the stress occurred for Type 1 runway pavement. Figure 18 also shows that the stress extends beyond the loading areas and this might be the reason of smaller stress values.
4.4 Stress contours of proposed multi-layer composite runway pavements under repetitive impacts

The performances of proposed multi-layer composite runway pavements were predicted under multiple impacts from Airbus 380 aircraft. In total, 100 impacts from aircraft were simulated with several loading steps. Figure 19 shows the stress contours of the asphalt concrete surface of proposed Type 1 multi-layer composite runway pavement under 100 impacts.

The maximum stress over the proposed multi-layer composite runway pavement (Type 1) surface after 100 impacts from aircraft was found as 6933 kPa which was 32% higher than the stress under single impact. The contours also show that the areas under maximum deflection also increased significantly for multiple impacts (100 numbers) compared to the single impact. The stress in the loading region for 100 impacts of aircrafts was 4045 kPa which was also 32% higher than the stress found for single impact at the loading area. The stress distribution was also found in concentrated pattern mostly within the loading region for multiple impacts whereas for single impact, the stress distribution was quite dispersed.
Figure 20 shows the stress contours at the top asphalt concrete surface for the proposed multi-layer composite runway pavement (Type 2) after 100 impacts of aircrafts. The area under maximum stress for 100 impacts of aircrafts was found to increase slightly compared to the deflected area under single impact of aircraft. The results of 100 impacts of aircrafts revealed that the 84% lower stress occurred for proposed runway pavement (Type 2) compared to proposed Type1 multi-layer composite runway pavement. The stress distribution was found as dispersed for the Type 2 runway pavement whereas the stresses were more centralized at the loading region for the Type 1 multi-layer composite runway pavement. The maximum stress at loading region was also 84% higher for the proposed Type 1 runway pavement compared to the proposed Type 2 runway pavement.

5. Parametric studies

Parametric studies were carried out on proposed Type 2 multi-layer composite runway pavement as shown in Figure 13 to explore the effects of impact loads from different aircraft, impact duration, compressive strength of base and sub-base materials and boundary condition. The FE model was developed as described in the previous sub-section. The effects of the parameters were investigated on the centre node of the load zone as shown in Figure 21.
5.1 Effects of type of aircraft

Three different types of large aircrafts like Airbus 380, Boeing 777 and Boeing 737 were selected to find the influence of mass and wheel configuration of the aircrafts in changing the deflection of proposed multi-layer composite (Type 2) runway pavement. Table 2 shows the mass and wing wheel configuration of the selected aircrafts.

| Type of aircraft | Total take-off weight (Ton) | Wheel configuration       |
|------------------|-----------------------------|--------------------------|
| L1               | Airbus 380                  | 2790                     | 4 wheel dual tandem      |
| L2               | Boeing 777                  | 1705                     | 6 wheel dual tridem      |
| L3               | Boeing 737                  | 404                      | 4 wheel dual tandem      |

Figure 22 shows that the highest maximum deflection was occurred for Boeing 777 which was around 0.61 mm, although Airbus 380 was heavier compared to Boeing 777. This happened because of wheel configuration of Boeing 777 (Table 2). The effect of closely fastened six wheels created more deflection compared to the four wheels during the hard impact of aircraft. The peak deflection for Airbus 380 was 0.55 mm which was 10% lower compared to the deflection created by Airbus 380 in the load zone. The total carrying weight including self-weight of Boeing 737 is about one quarter of Boeing 777 and so lower deflection of around 0.16 mm was found for the impact of this aircraft.

5.2 Effects of impact duration of aircraft

The impact duration of the aircraft can be varied for the landing of each aircraft. So, the effects of the three impact duration like 0.01 sec, 0.05 sec and 0.1 sec were studied to find its significance. The time range was...
selected as impact load is one category of impulsive force and the range was reasonable to predict the behaviour of any structure under impulsive force. Figure 23 shows the variation of deflection histories for three different impact times.

Figure 23 shows that the highest deflection occurred at 0.05 sec impact duration which was about 1.04 mm and it was almost double of the maximum deflection occurred at 0.01 sec. However, maximum deflection was found to decrease with further increase of impact time and 0.87 mm deflection was found for impact time 0.1 sec. Thereby, the impact time is a significant parameter in the prediction of surface deflection of multi-layer composite runway pavement under aircraft impacts.

Fig. 23. Effect of impact duration in the variation of top surface deflection of Type 2 multi-layer composite runway pavement

5.3 Effects of compressive strength of base layer

The effects of compressive strength of base layer of the proposed multi-layer composite (Type 2) runway pavement in changing the surface deflection were also studied.

Fig. 24. Effect of compressive strength of base layer in the variation of top surface deflection of Type 2 multi-layer composite runway pavement
The compressive strengths for base layer which was made up of concrete were selected as 35 MPa, 65 MPa and 80 MPa. Figure 24 shows the deflection histories for these three different compressive strengths of base layer. Figure 24 shows that the maximum deflection was highest for normal strength concrete of 35 MPa which was around 0.57 mm. The deflection was found to reduce when the strength of concrete was increased up to 65 MPa. Almost 7% decrease in deflection was found when high strength concrete was used in the base layer instead of the normal strength concrete. However, negligible reduction in deflection was found when very high strength concrete of 80 MPa was used.

5.4 Effects of compressive strength of sub-base layer

The effects of compressive strength of sub-base layer of the proposed Type 2 multi-layer composite runway pavement in changing the surface deflection of it were also studied. The compressive strengths for sub-base layer which was made up of cement mortar were selected as 10 MPa, 20 MPa and 30 MPa. Figure 25 shows the deflection histories for these three different compressive strengths of base layer.

![Figure 25: Effect of compressive strength of sub-base layer in the variation of top surface deflection of Type 2 multi-layer composite runway pavement](image)

Figure 25 shows that the maximum deflection was highest for cement mortar of 10 MPa which was around 0.55 mm. The deflection was found to reduce when the strength of cement mortar was increased slightly up to 30 MPa. In average 4% reduction in deflection was found for each 10 MPa increase in compressive strength within the selected range. The impact energy absorbed by the base layer is higher than the sub-base layer and so less significance is found for the compressive strength of sub-base layer.

5.5 Effects of boundary condition

The effects of boundary conditions in changing the surface deflection of proposed multi-layer composite (Type 2) runway pavement were studied to find its significance (Figure 26). The base of the multi-layer composite runway pavement was fixed and for sides of the large scale pavement model, three different boundary conditions like roller, pinned and fixed were selected.
Fig. 26. Effect of boundary condition in the variation of top surface deflection of proposed multi-layer composite (Type 2) runway pavement

For all types of boundary conditions at sides of the multi-layer composite runway pavement, exactly same deflection was found. This is acceptable because of this large pavement model and impact loading near the centre of the pavement. The deflection at point shown in Figure 21 which was close to the centre of the runway pavement should not be affected by the side boundary conditions.

6. Conclusions

The paper presents an experimental investigation carried out on a conventional composite specimen generally used as runway pavement in Australia and also on a proposed multi-layer composite runway pavement specimen. Two specimens were tested by drop weight impact tests and surface deflections over the top of the asphalt concrete surface layer were measured during the test. A 3D FE model was developed in ABAQUS and the model was validated using the self-performed impact test results. The results of FE analysis were found in good agreement with the experimental results. Furthermore, the performances of two proposed multi-layer composite runway pavement models were compared by FE analysis. The core findings of the study are summarized below:

- Proposed runway pavement specimen composed of rigid base and stabilized sub-base performed better compared to the Australian standard multi-layer composite runway pavement specimen during the drop weight impact test.
- The performance of rigid base and sub-base by using concrete and cement mortar respectively was found effective in the reduction of surface deflection of top surface layer compared to the stabilized sub-base for single impact and multiple impacts. The stress concentration over the loading area also found to reduce with rigid sub-base by using cement mortar.
- Closely connected six wheels of aircraft were found to create more surface deflection compared to the four-wheel group of aircraft.
- The influence of compressive strength of concrete in the base layer of the feasible multi-layer composite was found to have no significant effects in changing deflection. So, normal strength concrete can be used when the multi-layer composite is under impact loading.
- The compressive strength of cement mortar was found as insignificant in changing surface deflection and hence normal strength mortar can be used in the proposed multi-layer composite runway pavement under impact loading.
- The effect of impact duration was found as quite significant parameter to predict the performance of multi-layer composite runway pavement under aircraft impact. The impact time of 0.05 sec was found to develop maximum deflection.
- The selected boundary conditions for the sides of the large scale multi-layer composite runway pavement model showed no change in deflection of the top surface of the pavement model.
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Data Availability

The processed data required to reproduce these findings cannot be shared at this time due to legal reasons.

Conflict of Interest

The authors declare that they have no conflicts of interest.