Journal of Transportation Technologies, 2022, 12, 346-356
https://www.scirp.org/journal/jtts
ISSN Online: 2160-0481
ISSN Print: 2160-0473

A New Approach in Design of a Pavement Reinforced by A Geosynthetic Layer in Severely Stressed Area of the Airport Pavement to Accommodate Stresses Imposed by Aircraft Landing and Ground Movements

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How to cite this paper: Yadav, D.K. (2022) A New Approach in Design of a Pavement Reinforced by A Geosynthetic Layer in Severely Stressed Area of the Airport Pavement to Accommodate Stresses Imposed by Aircraft Landing and Ground Movements. *Journal of Transportation Technologies*, **12**, 346-356.
https://doi.org/10.4236/jtts.2022.123021

Received: April 29, 2022
Accepted: June 25, 2022
Published: June 28, 2022

Abstract

Pavements of airport runway and apron are subjected to stern stresses imposed by landing and ground movements of aircraft. The stresses are primarily concentrated in touchdown zone and wheel path areas of the pavement structure. This paper proposes that this area can be designed using geosynthetic layer reinforcement to minimise deflection and deterioration of the structure. The reinforcement can reduce the vertical stresses on the underground fuel pipes in the apron area, if used. The concept of ditch conduit reinforcement is suggested where a geosynthetic layer is used within a soil backfill to redistribute load over a conduit leading to stress redistribution. It is observed that the vertical load is significantly reduced by the arching action of the soil mass overlying the conduit. The load can be reduced further by placing a geosynthetic reinforcement layer within the soil backfill above the conduit. It is suggested that the inclusion of a geosynthetic layer in the granular backfill reduces the vertical load on a ditch conduit and the amount of reduction depends upon the tensile modulus, deflection of the geosynthetic and soil arching action. This leads to believe that a reinforced pavement structure for runway and aerodrome apron area improves the load carrying capacity of the pavement to sustain the operations of heavy transport aircraft, including occasional overloading of the pavement. Hence, this paper explores a possibility of using a geosynthetic layer under the runway pavement to provide reinforcement.

Keywords

Aircraft, Airport, Aeronautical, Aviation, Apron, Engineering, Pavement,

Runway, Structure

1. Introduction

The runway pavement at touchdown zone during aircraft landing experiences severe stresses imposed by the aircraft landing loads. The loads cause more deflection and deterioration of the pavement in that area as compared to other parts of the runway. Similarly, thickness of the tarmac structure at apron and aircraft parking bays of airports has been a major issue for engineers and maintainers of the pavements. Apron area of the airport also comes under similar stresses due to transfer of loads by the aircraft landing gears to the tarmac structure. Movements of the aircraft on ground, such as parking and taxing impose static and dynamic load on wheel-path area of the pavement structure. In the past, the aircraft were slow and light in weight as compared to the current transport aircraft, such as Airbus 380. With current usage of these heavy transport aircraft having all up weight of over 550 tones as compared to their older counterpart weighing less than 400 tones, the empirical methods recommended by the International Civil Aviation Organisation (ICAO) for airport pavement reinforcement and design need to be reviewed. Additionally, a new approach for designing a reinforced pavement of runway and apron is required.

As the stresses caused by the load are primarily concentrated in narrow area, such as wheel-path, the affected area can be reinforced similar to a ditch conduit reinforcement. Shear resistance caused by soil arching action can be reduced by providing a reinforcement below a pavement. According to [1], the arching element is restricted by principal planes of zero shearing stress surfaces. Therefore, moment equilibrium requires constant stresses in the arch. Consequently, the element of uniform density and thickness will cause a catenary shape. However, for arching action to be useful, the catenary must dip downward. Hence, the structure of this area can be designed using a geosynthetic layer reinforcement to counteract the stresses. It may minimise deflection and deterioration of the structure. [2] has identified geogrids as the most popular geosynthetic materials for the reinforcement. The researchers found that the geogrid reduces vertical deformation, if it is placed at a depth of the pavement. According to their results, 35% reduction in deformation of the pavement can be achieved by placing the geogrid at 360 mm depth. The deformation reduction varies according to the depth, but it provides optimal result if placed at the base of the base layer of the pavement. This study discusses the possibilities of using a geosynthetic layer in touchdown zone and the aircraft wheel-path areas of the apron similar to the geosynthetic layers used for ditch conduits to accommodate vertical stresses. Buried pipes are used under the apron area to carry fuel for aircraft refueling on passenger bays at airports. The reinforced pavement structure can also protect the buried fuel pipes in the area by reducing the vertical loads of the aircraft movements on the apron.

This study suggests that the use of geosynthetics can reduce vertical stresses over buried pipes or base-course and subgrade in the pavement structure of a runway. An example of ditch conduit reinforcement is used to illustrate the concept. The study is aimed at developing a new approach for reinforcing the pavement structures of runway and apron with geosynthetics to reduce vertical stresses caused by the aircraft landing and ground movements in touchdown zone and wheel-path areas of the apron. This research also presents a methodology for the installation of a geosynthetic layer within the soil backfill over a conduit in a ditch to reduce the vertical load. The geosynthetic layer reinforcement may help in designing the runway and apron pavements, which can support heavy transport aircraft operations without increasing the slab thickness of base-course of the pavements.

2. Current Pavement Reinforcement Practices

According to [3], the choice of the pavement is determined by evaluating aircraft mass, load distribution, soil conditions and the relative cost of alternative materials. Reinforced concrete is routinely used at aerodromes serving the largest commercial aircraft where greater strength and durability are needed. As a minimum, most aerodromes require an asphalt tarmac surface to satisfy strength, drainage, and stabilization criteria. Turf and cement-stabilized sand aprons have also been satisfactorily used in some locations. Reinforced concrete is usually more expensive than asphalt to install, but it is less expensive to maintain, and it usually lasts longer. In addition, concrete is relatively unaffected by spilled jet fuel, whereas asphalt surfaces can be damaged, if fuel remains on the surface even for a short period. This problem can be partially solved by coating the asphalt with special sealants and by frequently washing off the pavement.

Some researchers have used glass fiber reinforced polymer (GFRP) mesh to reinforce the runway pavements. For example, [4] examined the impact fatigue behaviour of a GFRP mesh reinforced engineered cementitious composites (ECC) for runway pavement application for a typical aircraft impact load with limited success, because they tested the reinforcement immediately above or below the pavement surface. According to them, it is better to place the mesh the bottom of the pavement as compared to the top surface. However, they recommend to place two layers of the mesh to achieve an optimum result. [5] recommends that the reinforcement of an existing flexible or rigid structure can be done by using same or different methods. Primarily, the choice for that is governed by technical and economic considerations. Nevertheless, the thickness of a flexible reinforcement can be obtained using following expression according to [5].

$$e = 3.75\left(F_{Xt} - X\right) \tag{1}$$

where, e, X, F are the equivalent thickness, thickness of the existing concrete slab, and coefficient of reduction of the thickness Xt, respectively. Xt is a theoretical thickness of the new slab less the existing slab. This is calculated considering the allowable stress and the corrected modulus k applicable to the existing slab. The equivalent thickness of the reinforcement must not be less than 20 centimeters unless special levelling courses are used to correct the deformations. Furthermore, due to joints and movements of the slabs, the concrete needs to be covered with a layer of material of sufficient thickness to prevent the appearance of defects at the surface.

Similarly, [5] suggests that the thickness of the rigid reinforcement can be obtained by using the following formula:

$$X_t = \sqrt[1.4]{X_T^{1.4} - CX^{1.4}} \quad (2)$$

where, C is a coefficient of quality of the existing slab, which is considered as 1, 0.75, 0.35 for the pavement in good condition, pavement exhibiting some cracking, and badly fragmented pavement, respectively.

However, Equation (2) applies only to the reinforcing slab placed directly on top of the existing pavement. When a layer of material is interposed between two slabs to alter profile of an existing pavement structure, the thickness of the reinforcement must be increased accordingly. Therefore, Equation (2) is to be used in following form:

$$X_t = \sqrt[1.4]{X_t^2 - CX^2} \quad (3)$$

Unfortunately, the empirical practices presented by Equation (3) apply only for reinforcing the existing structure. The expressions mentioned in this section do not provide solutions for the reinforcement used during initial design and construction of a cost effective and lighter structure than the currently used massive slabs to accommodate the high stresses caused by movements of heavy transport aircraft of present era. Some researchers have explored a possibility of using cellular geosynthetics reinforcement for sod pavements. [6] found that the load-bearing capacity of a sod runway pavement reinforced with a cellular geosynthetic system and using subsoil improvement technology can be improved by 30%. However, this improvement is a combined effect of using the geogrid and improving subsoil layers, the researchers have confirmed.

3. Load Applied on Airport Pavements and Buried Structures

The aircraft weight is transmitted to a runway and apron through its undercarriage during landing, taxing, and parking. Structure of a runway or an apron pavement depends upon the subgrade strength, thickness requirement, type, and design procedure pattern to determine the aircraft loading that the pavement can support [5]. With an extensive network of airports with paved and unpaved runways around the world, the cost of maintaining or replacing the pavements can be astounding. Furthermore, deteriorated pavements affect the aircraft structure and the life of landing gears that consequently affects airworthiness of the aircraft. As a result, the cost of flight operations and aircraft maintenance increases.

Either heavy loading or a high frequency of loading or both may possibly shorten the design life of a pavement as a consequence of deterioration. However, a pavement can sustain a definable load for an expected number of repetitions during its design life. Occasional minor over-loading is acceptable with only limited loss in pavement life expectancy, but civil aviation regulations require that the runway must be inspected for surface friction, slipperiness, roughness, cracks, and rutting at a predetermined interval [7]. Furthermore, the pavement structures of the runways and aprons are required to meet the international standards recommended by ICAO Annex 14 [3]. The frequent deterioration of the pavements occurs in the aircraft wheel-path areas due to high stresses imposed by aircraft movements on the pavement. According to [8], cracking in a concrete pavement due to tensile stresses are caused by applied cyclic loads. Statically, the concrete plates of the pavement can be described as thin plates residing on an elastic foundation. They are subjected to variable loads applied on aircraft wheel path area. [8] explored steel reinforcement in this severely affected area of the pavement and found it to be effective in mitigating the deterioration caused cracks.

A closely scheduled preventive and on-condition maintenance of the pavement to ensure safety of the aircraft and to meet the aviation regulatory requirements is required. Consequently, it adds cost to the airport owner and causes disruption to the flight schedules at airports by preventing the aircraft operations when the pavement is undergoing maintenance. Similarly, the stresses also affect the buried pipes in apron and taxiways of the airports. The apron area of a typical airport contains a network of buried pipes for aircraft refueling. These fuel lines are laid throughout the apron area closer to aircraft parking bays having outlets for refueling the aircraft. Therefore, the buried pipelines also come under the stresses transferred through apron pavement by taxing or parking loads of the aircraft in that area. Hence, a new approach of reinforcing the pavement structure by geosynthetics at touchdown zone on the runway and apron area during initial design and construction stage may be required to reduce the stresses and deterioration of the structure. Similar reinforcement may also be used in the aircraft wheel path areas to accommodate the stresses caused by the aircraft movement loads while taxing or towing the aircraft on taxiways and parking bays.

4. Reinforncement Installation Approach

Historically, the underground conduits or buried pipes are being used in wide applications since ancient times for carrying water, oil, gas, sewage, slurry, and similar materials from one location to another. A conduit placed in a relatively narrow ditch is known as a ditch conduit and it is often covered with locally available unreinforced earth fill as shown in **Figure 1**. The backfill load acting on the ditch conduit is generally less than the weight of the overburden backfill and the reduction in load on the conduit happens due to mobilization of shear resistance along walls of the ditch during settlement of backfill within the ditch. This is known as soil arching action [9].

The runway and apron pavements are subjected to both dynamic and static loading due to the aircraft landing, taxing, and parking. However, the dynamic loading has a greater effect in the touchdown zone and wheel-path areas due to the aircraft landing impact and taxing loads. Design for the wall thickness of a conduit is greatly dependant on the load acting on it and a situation may arise where a conduit having the wall thickness equal to or greater than the designed thickness is not available for installation. In such situations, a conduit of smaller thickness cannot be recommended until the load is reduced. This may bring a usage constraint to a typical apron for the heavy aircraft. Placing a geosynthetic-reinforced soil backfill as shown in **Figure 2** can be considered as an option to address such issues.

[11] indicates that the vertical load on the conduit decreases the overburden pressure with an inclusion of a geosynthetic layer within the backfill cover. The reduction in the vertical load occurs due to the distribution of the load by membrane action of the geosynthetic has also been confimed by [12]. The role of geosynthetic

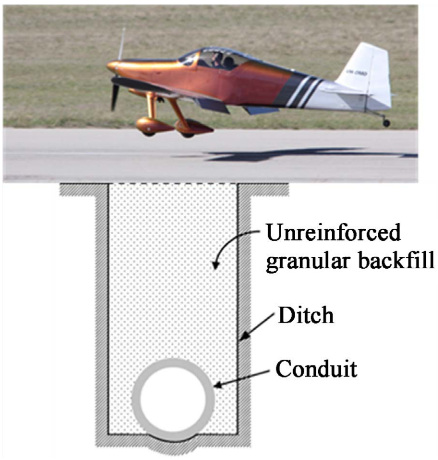

Figure 1. A buried conduit covered with unreinforced granular backfill (adapted from [10]).

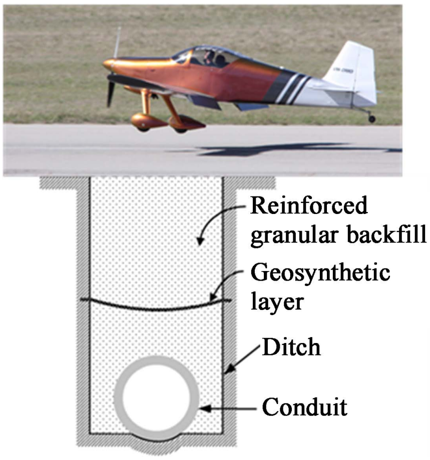

Figure 2. A buried conduit covered with geosynthetic-reinforced granular backfill (adapted from [10]).

in these applications may be compared with the soil arching action that results in reduction in the load on the ditch conduit when the overlying backfill settles. [10] argues that a geosynthetic layer anchored withing the wall above the conduit can further reduce the load on the conduit. The resrachers believe that the geosynthetic arching action is similar to the soil arching in this situation. This results in tranfering the load to the ditch walls.

Therefore, the geosynthethic reinforcement can also be used in runway touchdown zone to reduce the stresses caused by heavy impact load of aircraft landing (Figure 3). This new concept of reinforcement will reduce the vertical stresses of the landing impact on the runway pavement. It may also improve the touchdown zone deflection characteristics of the runway pavement. As a result the runway capacities of accommodating the landing impact loads of heavy transport aircraft without increasing the slab thickness of the pavement in the touchdown zone can be improved. The reinforced runway pavement will also able to sustain occasional overloading due abnormal maneuvers of aircraft in emergency situations, such as hard landings or rejected takeoffs.

Technically, installing a geosynthetic layer as shown in Figure 2 may be a difficult task. As a solution, a vertical section of a ditch with a conduit of circular cross-section installed at its bottom may be considered. Therefore, the actual width of the ditch and the geosynthetic layer must be greater than the width of the conduit, so that a proper anchorage of geosynthetic edges can be provided for geosynthetic arching action (Figure 2). Similarly, the geosynthetic at both ends should extend beyond the width of the ditch and it must be covered with well compacted backfills. This can easily be done at most construction sites both manually or mechanically. Likewise, the minimum length required on both sides is governed by the backfill-geosynthetic interface shear resistance, which can be determined by a pullout test [14]. The geosynthetics can be a woven geotextile, a geogrid or a reinforcement geocomposite, but it must be ensured that the material is capable to perform the reinforcement function.

5. Results and Discussion

According to Figure 2, the forces act on the ditch conduit according to its outside

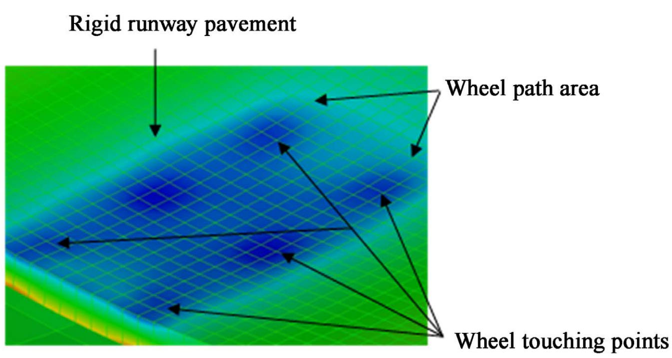

Figure 3. Rigid runway pavement showing stress peaks at wheel touching points in the touchdown zone (adopted from [13]).

diameter and depth measured from ground level to top surface of the conduit. Therefore, a thin horizontal element of the soil-backfill located at a depth below the ground level and the geosynthetic layer installed at a known depth above the top of the conduit. It can be observed from **Figure 2** that the geosynthetic layer is being deflected under the load with maximum vertical deflection (rut depth) at the center of the ditch. Therefore, the shape is assumed to become parabolic. However, if the geosynthetic layer does not deflect, its presence will cause no reduction in the load on the ditch conduit, which is an expected observation. Likewise, the geosynthetic will not be able to reduce the load on the conduit, if it is placed at top level of the conduit or at top level of the ditch or the stiffness of the geosynthetic is very low. A different installation method used by [15] also indicates that the use of geosynthetics can reduce vertical stresses over buried pipes. Unlike beams and plates that can carry bending moments and shear forces, the geosynthetic has to deflect to maintain equilibrium when subjected to normal loads. [10] has calculated the load coefficient for vertical load at horizontal level of the geosynthetic layer for the reinforced soil backfill case, and when there is one layer of anchored geosynthetic present above the buried conduit covered with a granular soil backfill. They also calculated the vertical load on the conduit for both reinforced and unreinforced situations. The analytical study had considered both flexible and rigid conduits. The researchers found that using a geosynthetic reinforcement within the backfill over the conduit reduces the load on the ditch conduit by 8.7%. They also confirm that the reduction in the load coefficient can be achieved by increasing both the geosynthetic stiffness and the rut depth. Similarly, the transfer of aircraft landing and rolling load from a runway pavement to the soil can be managed more efficiently using a geosyntheic layer below the pavement.

Therefore, the use of geosynthetics discussed in this paper can significantly enhance the operating capabilities of a runway, because all runways are classified according to their strength, and they are given a load classification number [16]. According to [17], the ICAO has adopted a pavement classification system for reporting airfield strength known as aircraft classification number (ACN) and pavement classification number (PCN). This system reports a unique PCN, which indicates that an aircraft with an ACN equal to or less than the PCN can operate on the runway pavement subject to any limitation on the tyre pressure. Similarly, in terms of overloading, a pavement can sustain a definable load for an expected number of repetitions during its design life. As a result, occasional minor overloading is accepted, but the ICAO recommends specific criteria for such situations [5]. Therefore, the use of geosynthetics in the touchdown zone and wheels path can increase the PCN and overloading sustainability of a runway. As a result, the heavier aircraft and higher frequency of flights can be operated on the runway without increasing the slab thickness, because the installed geosynthetic layer can reduce the vertical stresses transferred to the pavement structure by the aircraft movement and landing loads. Likewise, the geosynthetic layers installed under aircraft wheel-path of the apron area can allow the use of buried fuel pipelines of lower wall thicknesses in that area as compared to the normal size pipes, because the membrane action of the geosynthetics reduce the vertical load indirectly exerted onto the pipes by the aircraft taxing and other movements.

6. Conclusions

The runway pavements in touchdown zone and apron area of an airport are severely stressed by aircraft landing and ground movement loads. Therefore, designing the pavements of sustainable thickness has become an important issue for engineers with introduction of heavy transport aircraft. Current pavement reinforcement and design practices are based on empirical observations. This study suggests a new approach in design of a pavement reinforced by a geosynthetic layer in severely stressed area of the runway pavement to accommodate the vertical stresses.

Primarily, the stresses concentration is more severe in touchdown zone and wheel path area of runways and taxiways of an airport. Therefore, the study uses an example of ditch conduit to illustrate the reinforcement concept. It is observed that the reinforcement can also protect the buried fuel pipes in the apron area by reducing the vertical stresses applied to the pipes. To protect these buried pipes used in the apron area to carry fuel for aircraft refueling, a practical method for reinforcing the granular soil backfill over the ditch conduit using a geosynthetic layer to reduce vertical load on the conduit is proposed in this study. As a result, an analytical model has been suggested for reduction of the vertical load on the conduit considering both the soil and the geosynthetic arching actions. It is observed that the inclusion of a geosynthetic layer within the granular soil backfill reduces the load on the ditch conduit. However, the amount of load reduction depends on the tensile modulus, the maximum deflection depth of the geosynthetic and geosynthetic arching actions. Nevertheless, the large reductions are possible for higher values of the tensile modulus and the rut depth. In conclusion, it can be stated that the installation of the geosynthetic layer as a reinforcement to the pavement structure in touchdown zone and aircraft wheel path areas is an attractive choice for pavements supporting the operations of heavy transport aircraft. It is also possible that the reinforced pavement structure will support the occasional overloading caused by emergencies, such as hard landings by aircraft.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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