Design of a Temporary Surface-Level Helipad Paved with Aluminium Mats

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Abstract

Lifelines are infrastructural networks needed to guarantee transportation and other utilities. However, natural, deliberate, or one-off events could trigger a crisis throughout the on-ground network services and require the use of air transport with airplanes and helicopters. This work presents the results of numerical analysis of a temporary surface-level helipad paved with preformed mats. Modular elements are composed of aluminium alloy, and their sides interlock with a roto-translating motion in order to have a continuous pavement. The study focuses on traffic loads transmitted by helicopters commonly used in Italy by forces responsible for law and order, civil protection, and emergency or rescue services. The study presents the computational results carried out using the software package ANSYS® R17.1. The examined pavement is composed of 4.1 cm-thick aluminium mats, a 30 cm-thick granular layer and a geotextile membrane on the roller-compacted subgrade. Six static load configurations have been examined: emergency and operating conditions for wheels on the centre of the mat, on transversal and longitudinal joints. The maximum values of stresses are within the elastic limit of the aluminium alloy, and the maximum deflections do not compromise the safety of circulation. The proposed approach could be used by emergency supply agencies because the examined solution has both interesting short- and long-term implications: it ensures immediate solution, but it can be dismantled and relocated once the emergency ends.

*Keywords:*helipad; helicopters; aluminium mats; emergency transport; ANSYS.

1. Introduction

Lifelines are network systems that are developed in the territory, on the surface, in elevation or in the subsoil and which relate and connect various spatial areas (Cirianni et

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al., 2012). They ensure essential and indispensable services for the people survival, e.g. transport, water and sewage, telecommunication, gas and fuels, electricity (Solari and Cimellaro, 2013). Road infrastructures are among the most important lifelines: most of the time any maintenance and repair operations of other lifelines require the use of road infrastructures (Li et al., 2011). Moreover, accessibility systems are essential not only for the ordinary life of regions and cities, but also and especially during the emergency (Moretti and Loprencipe, 2018), as they allow the connection between affected areas and areas from which the rescue can arrive, and to which evacuated people can be transported (Li and Liu, 2018).

However, the proper functioning of road lifelines and their functionality are not ever appropriate to the needs in scheduled conditions and/or after a natural disaster (Su et al., 2013). These conditions can occur when one-off event is scheduled in an area whose existing transport network does not satisfy the demand, or after seismic and meteorological events, when the existing on-ground transport network is seriously damaged (Xue et al., 2012). Such logistics or emergency needs could lead to adopt air transport operations with airplanes and helicopters. The last ones offer a more versatile utility service than the formers (Loveless et al., 2009). Indeed, emergency evacuation, site inspections, special events often require the use of materials for rapid repair (Roh et al., 2015; Jung et al., 2014) or construction of temporary helipad to be quickly constructed (Gopal, 2006) and, after, dismantled. Preformed metal mats are currently used to pave helipads: they are lightweight and compact prefabricated elements suitable for rapidly having helicopter approach and take-off zones. The panels are usually composed of 4 cm-thick aluminium cells, and their strength even allows the use for both recess and covering execution in airport (Leonelli et al., 2017). These modular interlocking elements are laid on the bottom granular layers, but they are compatible with other surfaces including concrete, rocky, grass, or irregular landing areas. Each module is composed of a hollow, extruded on-piece main section with moulded end connectors at each long side (NAVSUP, 2001). Therefore, the direction of the maximum thermal expansion is normal to the short side: this condition avoids undesirable effects of thermal effects and prevents the complete tightening of longitudinal joints.

The long sides of mats interlock with a roto-translating motion in order to have a continuous surface, to form non-separable joints, and to improve the load transfer between surrounding units (Figure 1).

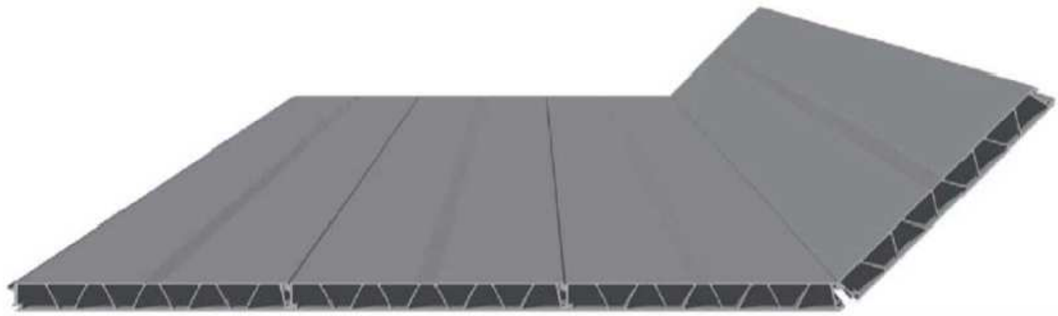


Figure 1: Example of metal mats.

The essential components of a heliport are areas suitable for lift-off, take-off, approach and touchdown manoeuvres (ICAO, 1995; ICAO, 2013). For surface-level heliports, the final approach and take-off area (FATO) is the area over which a vehicle completes the approach or begins take-off procedures; in this area, helicopters may also touchdown and take-off. The FATO shape is at least a circle whose diameter is 1.5 times the over-all length (OL) of the longest helicopter (Figure 2).

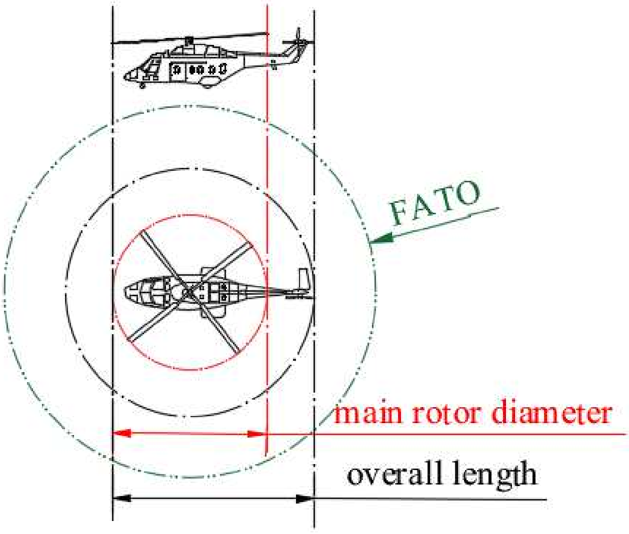


Figure 2: Physical characteristics of FATO and helicopters.

According to FAA (2012a) and the Italian Civil Aviation Administration(ENAC, 2011), the FATO bearing strength should cover three design loads under different conditions:

1 static load (i.e. the load equal to the helicopter's Maximum take-off mass (MTOM) applied through the contact areas of the wheels or the afts of skid-equipped helicopter);

2 dynamic load (i.e. the load which occur for 0.2 s or less duration during a hard landing applied through the contact areas of the main landing gear);

3 rotor load (i.e. the downwash load which is not more than the weight of the helicopter distributed uniformly over the disk area of the main rotor).

According to ICAO (1995), the FATO bearing strength should cover an emergency landing with a rate of descent of 3.6 m/s and the design load is 1.66 times the Maximum take-off mass (MTOM) of the heaviest helicopter.

The Italian Air Force (3nd Department of Genio located in Palese - Bari) is studying modular solutions to pave temporary helipads when on-ground transport network cannot satisfy the needs. The aim of this paper is to present the overall design process of a surface-level helipad to be used in emergency or one-off condition. The verification of the mechanical performance of the mat pavement was conducted using the Finite Elements Model (FEM) approach: a mesh discretization divides the continuous domain of the pavement into a set of discrete sub-domains to obtain a numerical approximation of the system mechanical response (Zoccali et al., 2018; Loprencipe et al., 2019). The software package ANSYS® R17.1 has been used in order to calculate the stress-strain conditions induced by the expected traffic loads because it is currently used to analyse pavement structures (Kohnke, 1982).

The importance of this work is that it provides the results of a structural analysis carried out to design a temporary surface-level helipad paved with aluminium mats. This building approach has both interesting short- and long-term effects: it ensures immediate solution to emergency and one-off problems, but it adopts removable and reusable elements. Therefore, it has a low impact on the surrounding environment due to production, construction, and disposal of mats.

2. Materials and methods

In order to make the infrastructure available to as many aircraft possible, the authors considered the geometrical and physical characteristics (Table 1) of the passenger transport helicopters commonly used in Italy and supplied to the Armed Forces, the civil Defence, the Police and helicopter rescue:

1 HH 212: it ensures search and rescue services, by night and by day, even with hard weather conditions;

2 HH-A101: it is a single-main rotor helicopter that performs multiple roles, including air support for special operations, slow mover interceptor and personnel recovery, in crisis areas;

3 AW-139: it ensures the air search and rescue service, both for crews and military tasks and for civil activities in case of emergency medical flights, natural disasters and major events often in prohibitive conditions, at night, with bad weather, in particularly inaccessible and isolated areas;

4 TH 500B: it can perform training duties, missions in SAR operations, people or goods transport, rescue operations, defence of bases and military installations, reconnaissance, observation and connection;

5 AB412: it ensures the search and rescue services, by night and by day, even with hard weather conditions;

6 EC.145C2: it ensures helicopter rescue.

Table 1:Geometrical and physical characteristics of commonly used in Italy helicopters.

Model	*Main rotor diameter (RD) (m)*	*OL (m)*	*MTOM (kg)*
HH-212	14.6	17.4	5,080
HH-A101	18.6	22.8	15,600
AW-139	13.8	16.7	6,800
TH 500B	8.0	9.39	1,361
AB412	14.0	17.8	5,298
EC.145C2	11.0	13.0	3,585

Note: *RD* is the diameter of the main rotor.

Data listed in Table 1 highlight the design helicopter is HH-101A because it has the highest dimension and the highest value of MTOM. Therefore, its technical characteristics are listed in Table 2 in order to design the FATO pavement having regard to economy, effectiveness and efficiency criteria. According to ICAO (1995), the FATO diameter was 35 m-long.

Table 2:Technical characteristics of HH-A101.

Characteristic	*Nose landing gear*	*Main landing gear*
Number of wheels	2	4
Wheels dimension (width x diameter, mm)	117.8 x 520.7	215.9 x 635.0
Pressure tire (kPa)	827	724
Collapse load per wheel (kg)	7,839	18,308
Contact area per wheel (cm^2)	214	380
Maximum static load (kN)	35.6	118
Maximum static load per wheel (kN)	17.8	29.5

Figure 3 shows the layout of the nose and main landing gears of HH-A101 (Agusta Westland, 2015).

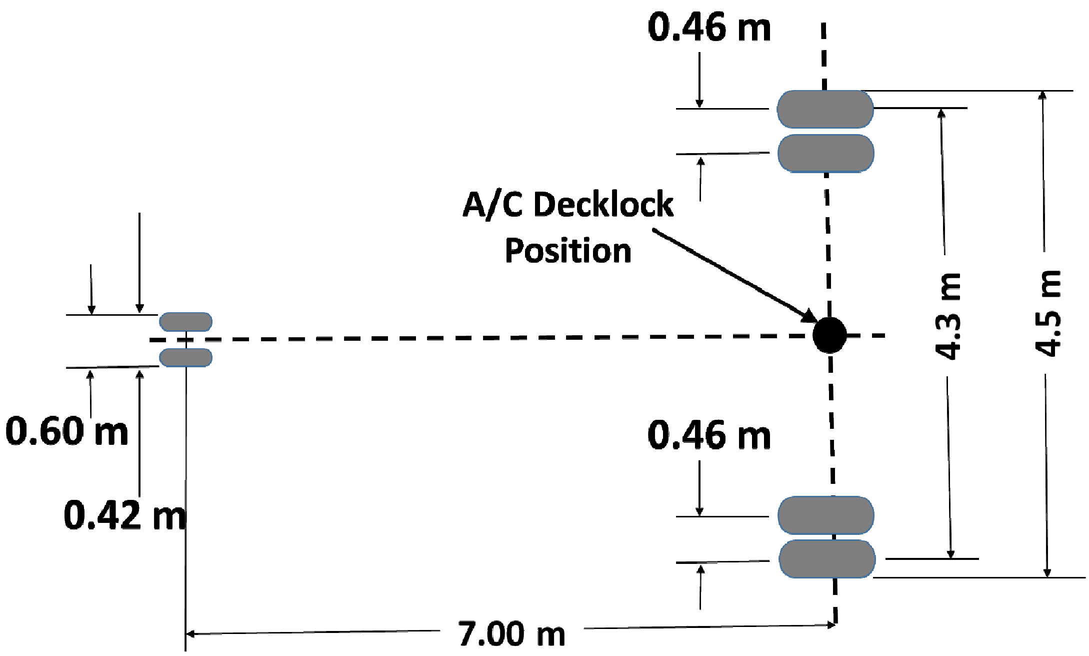


Figure 3: Nose and main landing gears of HH-A101.

According to (FAA, 2012a), the pavement verification was carried out considering conditions both of the ultimate limit state (ULS), when the aircraft lands in emergency, and of the ordinary exercise (helicopter parked with staff present). The applied loads are perpendicular to the pavement because the helicopter is a vertical take-off and landing (VTOL) aircraft, and it was supposed that the design helicopter is properly trimmed. Indeed, during flight the thrust provided by the tail rotor (Zhu and Van Nieuwstadt, 1996) counters and neutralizes the torque effect created by the main rotor. Moreover, during an approach anti-torque pedal corrections compensate for collective changes (FAA, 2012b).

The ULS analysis has been carried out according to the ICAO Heliport Manual Doc (ICAO, 1995) that provides guidance in constructing surface level heliports, elevated heliports, and helidecks located on offshore installations or ships. Particularly, Chapter 1 is about site selection and structural design of these infrastructures and it states that the FATO area should support an emergency landing with a rate of descent r equal to 3.6 m/s. Therefore, the design static load for ULS analysis is 1.66 times the maximum take-off mass of the heaviest helicopter for which the FATO is intended (ICAO, 1995). This approach summarizes all dynamic loads induced on the pavement during an emergency landing. Particularly, it takes into account the dynamic load of 0.2 s or less duration d that may occur during a hard landing (FAA, 2012a).

Indeed, when the helicopter lands, its change of momentum M (Equation 1) causes an impulse of force applied on the pavement.

$$M = MTOM \cdot r \qquad (1)$$

Therefore, the main landing gear, which is the most critical one (Table 2), transmits to the helipad a vertical force Fm (Equation 2) equal to 216 kN.

$$F_m = UCM \cdot r/d \qquad (2)$$

where UCM is the maximum mass of the main landing gear (i.e. 12,029 kg). Figure 4 shows the design loads (F) for ULS analysis, in which MTOM is applied to the pavement by the main landing gear of the wheel-equipped HH-A101.

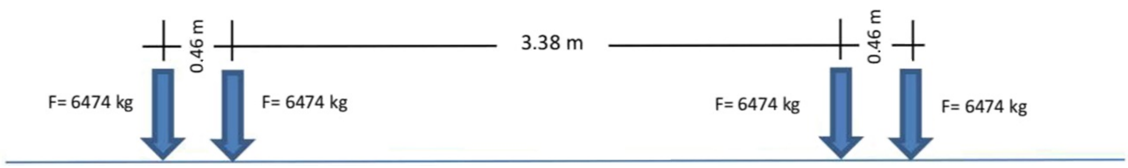


Figure 4: Design loads for ULS.

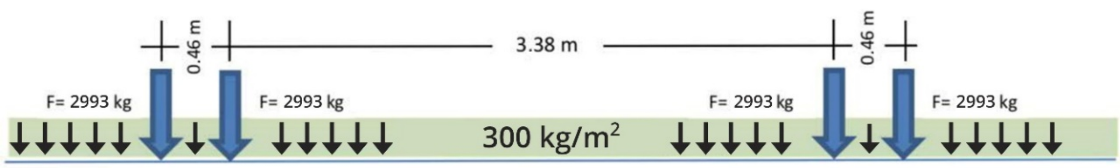
Therefore, the static FEM model applied on the heliport pad the overall load L equal to 254 kN (Equation 3)

$$L = 4 \cdot F \cdot g = UCM \cdot 1.66 \cdot g \qquad (3)$$

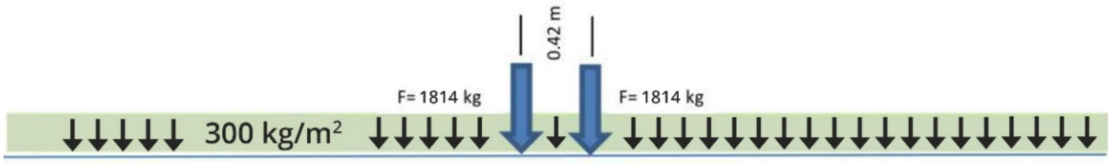
where g is the gravitational acceleration.

L is more than Fm, therefore the proposed static model correctly describes the dynamic landing conditions.

For the analysis of operating conditions, a uniform distributed load (q) equal to 300 kg/m^2 has been considered. It is an overall superimposed load which takes into account both the rotor downwash effect (FAA, 2012a), and the presence of personnel, freight, refuelling equipment and any appendages on the deck surface (according to the Italian standard about civil constructions (Italian Ministry of Infrastructures, 2008). This superimposed load is applied on the whole FATO, and it is added to the MTOM. The static distribution of masses on the pavement is in Figure 5a (main landing gear alignment) and Figure 5b (nose landing gear alignment).



(a)



(b)

Figure 5: Design loads for operating conditions: (a) main landing gear; (b) nose landing gear.

In the analysis of the helipad pavement, critical wheel loads were modelled as a tire pressure uniformly distributed within an ellipse whose major axis is 1.7 times as long as the minor one.

The helipad pavement was composed of:

- aluminium mats;
- 30 cm-thick granular layer composed of a compacted unbound layer (Table 3);
- a geo-textile membrane;
- roller-compacted subgrade.

Table 3:Mechanical characteristics of foundation material.

Material property	*Value*
Young's modulus (MPa)	100
Poisson ratio (-)	0.3
Shear modulus (MPa)	38
Friction angle (°)	35
Residual friction angle (°)	25
Cohesion (MPa)	0

The subgrade bearing capacity was defined through the resilient modulus of the soil, and it was equal to 30 MPa.

Each mat weights not more than 40 kg, in order to be handled by two people. Its upper side should provide a water-impervious and skid-resistant surface: the British Pendulum Number (BPN) calculated according to the standard EN 14231 (2003) is not less than 45. Table 4 lists the geometrical dimensions of each examined module.

Table 4:Geometrical characteristics of a single mat.

Dimension	*Value*
Length (cm)	400
Width (cm)	25
Depth (cm)	4.1

Mats are composed of an aluminium alloy (i.e. EN AW 6063) (EN, 2013), whose mechanical characteristics are in Table 5. These values have been used in the numerical simulation.

Table 5:Mechanical characteristics of the aluminium alloy.

Material property	*Value*
Density (g/cm^3)	2.71
Young's modulus (MPa)	69,000
Poisson ratio (-)	0.33
Shear modulus (MPa)	26,000
$Y_{0.2}$ 0.2% (MPa)[1]	200
yield stress (MPa)	245

[1] $Y_{0.2}$ is the yield stress is the offset yield point at which 0.2% plastic deformation occurs.

For the mechanical boundary conditions, "bonded" contacts have been modelled to describe the interaction between the mats, and "no separation" ones to describe the ground-structure contact. The horizontal displacements on its sides were restrained to represent the confinement due to the surrounding ground, while the bottom layer (i.e. the subgrade) was fully constrained.

In order to analyse the effect of the loads, on a 1 m-wide section (plain-strain model) the design loads have been applied. This analysis highlighted that stresses and strains induced by the design loads are confined within a circumscribed around the tires area of 1 m^2 and within a depth of about 50 cm from the laying surface. For this reason, the distance between the three contact areas does not influence the mutual effects on the pavement and the FEM analysis has been limited to the load of one semi-main landing gear. Six load configurations were examined, as listed in Table 6: three refer to emergency (E) conditions, three to operating (O) conditions.

Table 6:Load configurations.

Wheel position	*Load configuration*	
	Emergency	*Operating*
Centre of mats	E-CM	O-CM
Longitudinal joints	E-LJ	O-LJ
Transversal joints	E-TJ	O-TJ

In the configurations E-LJ and O-LJ, one of the major axes of the load area was parallel to a longitudinal joint; in the configurations E-TJ and O-TJ, one of the minor axes of the load area was parallel to a transversal joint; in the configurations E-CM and O-CM, the load area was contained within mats (Figure 6).

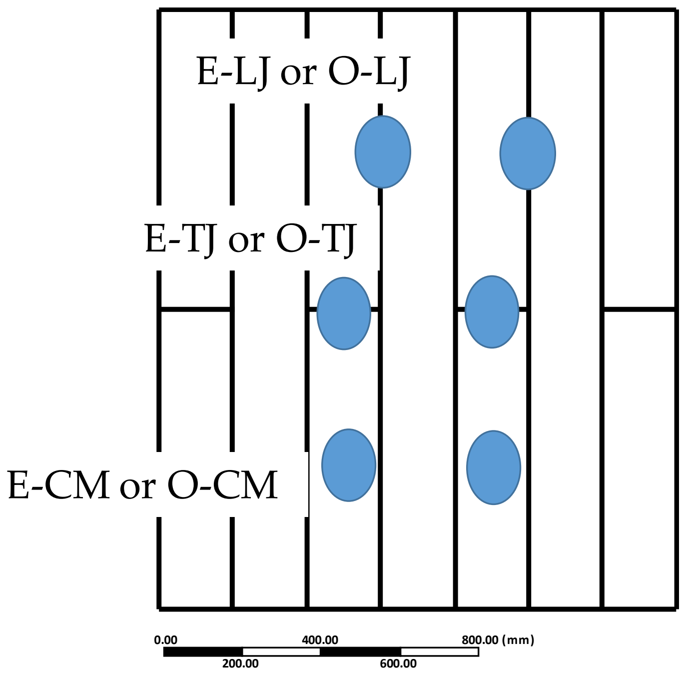


Figure 6: Load configurations.

Each model was 1.75 x 1.75 x 0.5 m and it was composed of 600,000 nodes automatically defined by the software.

3. Results

Six FEM models representing three emergency and three operating load conditions on a surface-level helipad were implemented to calculate the maximum stresses and strains induced by the critical helicopter. A Dynamic Amplification Factor (DAF) equal to 1.66 has been applied to the MTOM in order to simulate the dynamic interaction between the design helicopter and the helipad during an emergency landing. Figure 7 to Figure 9 show the vertical deformation layouts of E-LJ, E-TJ, and E-CM conditions, respectively.

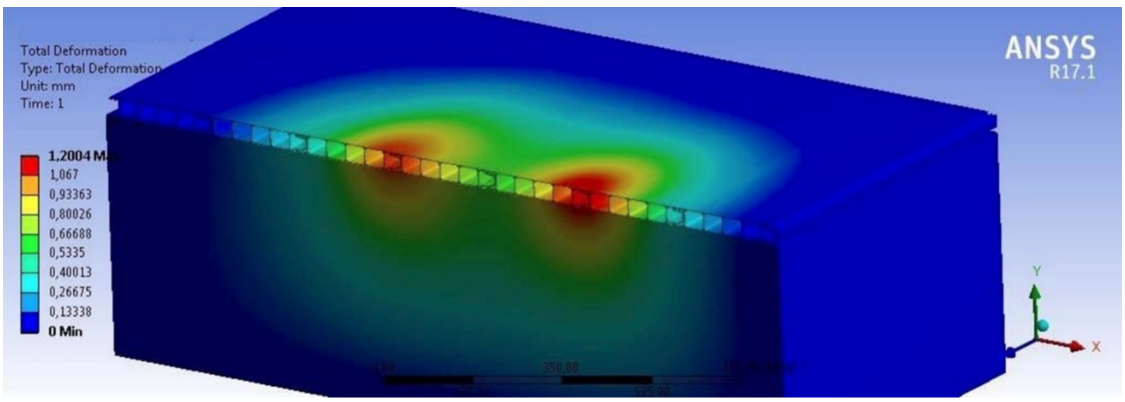


Figure 7: Deformation layout of E-LJ condition.

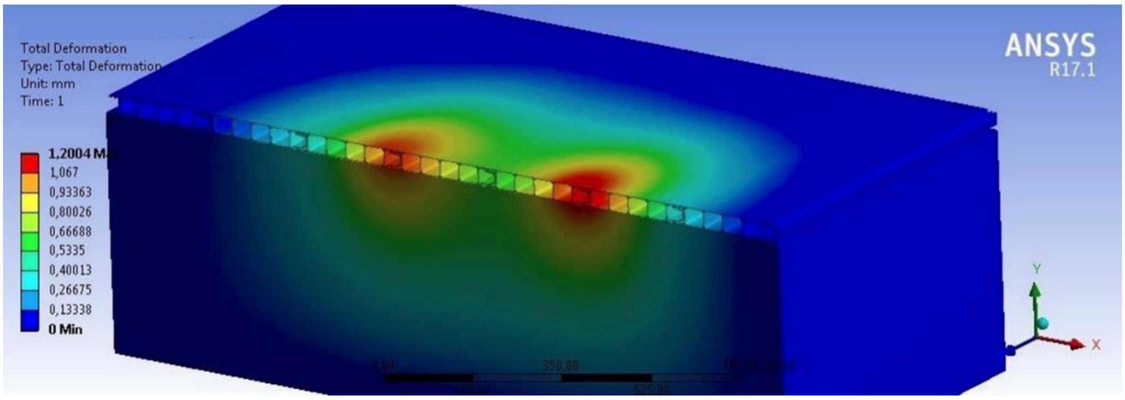


Figure 8: Deformation layout of E-TJ condition.

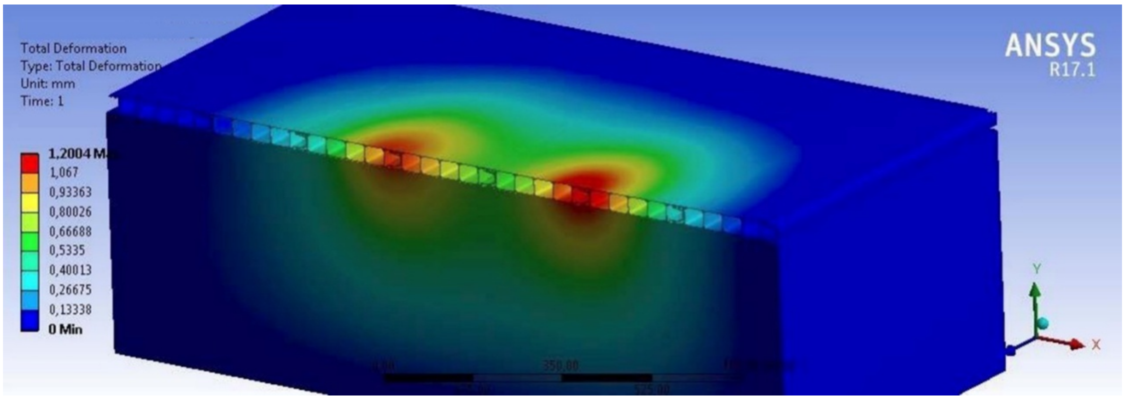


Figure 9: Deformation layout of E-CM condition.

The results highlight the correct size of the modelling areas: stresses and strains are zero near the edge of the model. Moreover, it is possible to appreciate the significant interaction effect from the dual wheel loading. This effect has its maximum impact for E-CM condition, when the vertical deformation between the two loading areas reaches its maximum value (i.e. 0.82 mm).

Table 7 lists the maximum values of stress and deformation calculated for emergency conditions (Figure 4).

Table 7:Maximum stresses and deformation for E conditions.

Load configuration	*Maximum tensile stress (MPa)*	*Maximum vertical deformation (mm)*
E-CM	92	1.13
E-LJ	99	1.20
E-TJ	80	0.98

All values listed in Table 7 are within the elastic limit of the aluminium alloy (i.e. $Y_{0.2}$ 0.2%). The highest ones are for the configuration CM: this result is justified by a small number of loaded mats. Indeed, the more is the number of elements involved by the load, the greater is the stress distribution (Di Mascio et al., 2019; Zoccali et al., 2017).

Table 8 lists the maximum values of stress and deformation calculated for operating conditions (Figure 5).

Table 8:Maximum stresses and deformation for O conditions.

Load configuration	*Maximum tensile stress (MPa)*	*Maximum vertical deformation (mm)*
O-CM	47	0.53
O-LJ	52	0.57
O-TJ	41	0.46

Values listed in Table 8 are within the elastic limit of the aluminium alloy, and the maximum vertical displacement of the helipad surface does not modify the FATO drainage system, therefore the pavement is verified (ICAO, 1995).

The obtained results could be used by emergency supply agencies when transport lifelines cannot satisfy the needs of people. Indeed, the examined solution has both interesting short- and long-term implications. Indeed, it ensures immediate solution to emergency and one-off problems (the time required for a helipad construction is in the order of few days), but it can be dismantled and relocated once the emergency ends.

4. Conclusions

The need for rapid construction of surface-level helipad has grown fast over the years, both for one-off events and for rescue operations. Therefore, there is the need for a technology that could be applied balancing conflicting objectives of safety and rapidity. Helipads paved with metallic mats are solutions often adopted because they quickly answer to transport demand and do not interfere with the surrounding environment. In Italy, the Italian Air Force (3nd Department of Genio located in Palese - Bari) analysed technical performances of aluminium alloy elements under helicopters commonly used by the Armed Forces, the civil Defence, the Police and helicopter rescue. Emergency and operative load conditions have been considered according to the ICAO Heliport Manual in order to calculate the induced stress-strain conditions. The software ANSYS® has been used for the verification of the mechanical response of mats within their elastic range. The ICAO heliport manual has been considered to define a static FE model, which took into account the dynamic forces applied through the contact areas of the wheels during an emergency landing.

The results from the analysis highlighted that the examined aluminium mats satisfy the verification both for emergency and ordinary conditions: the maximum tensile stress is 103 MPa, while the elastic limit of the aluminium alloy is 200 MPa. In the examined case, the input data about design loads and subgrade bearing capacity are severe: traffic loads are high (i.e. MTOM of the design helicopter equal to 15,600 kg), while the subgrade performance is poor (i.e. subgrade resilient modulus equal to 30 MPa). Therefore, the results could provide a framework and a reference for any further less-burden specific case. The results demonstrate that modular interlocking elements laid on granular layers can satisfy logistics or emergency needs when on-ground transport network cannot do it.

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