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The Use of Engineered Materials Arrestor System in Emergency Landings of Helicopter

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ABSTRACT: Today, the use of helicopter as a fast and relatively safe facility has been expanded compared to other vehicles. To control the helicopter, different parts of it should cooperate well. Deficiency of each part leads to disruption of helicopter operation. Failure of tail rotor as one of the main parts of the helicopter, leads to failure of resistant torque of the helicopter and the helicopter loses normal landing ability. In this situation, running landing is suggested to the pilot. In this maneuver, expanded land is required, which is difficult to select in mountainous areas. In this study, energy absorption bed is used to reduce landing area and the distance traveled during landing. Different materials have been introduced for energy absorption bed, in this study one of the best and newest materials is applied, glass foam (sponge foam) and foamed concrete. Abacus finite element software was used for simulating helicopter landing on energy absorber bed. Helicopters with different weights and various asphalt and concrete landing bands were used to consider real situation. According to software analysis data, it was concluded that helicopters with high weight travel more distance than materials with higher elasticity module; the less the elasticity module of the bed, the more energy absorption power. In the case of lack of energy absorption bed, helicopter will stop after 1000 m, while the energy absorption bed reduces the distance to less than 100 m. Regarding the small dimensions of energy absorption bed, it has ability to be applied in mountainous area to show better performance in stopping the helicopter.

Keywords: Helicopter, Energy Absorption Bed, Glass Foam, Concrete Foam, Abacus, Finite Element

INTRODUCTION

Helicopter is an aircraft that its take off and propulsion is done by one or two large horizontal rotors. Its main particles and their tasks can be summarized as (Handbook, 2012):

1. Body: the main part of helicopter that other parts are attached to it or mounted on it. Passenger's cabins, pilot's cockpit, fuel tanks and electronic systems are also fit in the body.
2. Motor: power generation unit for rotation of main blade, tail rotor, hydraulic and pneumatic pumps, energy generators, etc. fitted on top of sides of the body in the form of pistons and jet (turbo shift).
3. Tail: used to put the tail rotor in suitable position.
4. Main rotor: set of main blades and their angle changing mechanisms that are responsible for lifting power generation.
5. Tail rotor: set of tail blades and their step angular changing mechanisms that are responsible for neutralization of main rotor torque.
6. Landing gear: installed to bottom of the body as skate or wheel, and is responsible to capture strokes on landing, to stabilize helicopter on the grounds, and to move the helicopter with wheels on the ground.

Rotation of main rotor applies torque power into the body, causing helicopter to spin around itself. To deal with this phenomena, various strategies have been considered, one of which is the use of tail rotor. Tail rotor is placed at the specified distance from the main rotor axis to the tail bar, to neutralize the torque caused by rotation of main rotor of the helicopter. When the tail rotor fails, helicopter will lose normal landing ability due to rotation around itself. In this situation, the pilot can use the fins angle or vertical stabilizers of the tail to lead the helicopter to land in suitable area. Fin operates such that the air flow generated by main rotor collide the angle applied in fin and causes the helicopter to remain stable. In this condition, the pilot adjusts the helicopter speed around 60 knot (111 km/h) (Young, 1983). At continue, the pilot use running landing for safe landing. This maneuver is done during the reduction of helicopter power due to high weight and engine shut down in high flight altitude, and partial failure of the engine during flight or in emergency mode of tail and stuck pedal failure. To do this maneuver, the pilot chooses a flat area without natural or human made obstacles. Helicopter can approach the ground with any angle, although the angle of 5 degree or less will minimize the power required to stop the helicopter when touching the ground. The pilot approaches the helicopter to the ground and on a moment attaches the helicopter with the ground and moves forward at a fast pace (Figure 1). The occurrence of friction reduces the speed and thus stops helicopter. With reduction of lift, the pilot heightens the helicopter to increase the landing gear friction with the ground and to stop the helicopter in shorter distance (Handbook, 2012). However, selecting an area with this condition is difficult in mountainous area with inappropriate topography. To solve the problem, energy absorption system is used in this study to stop helicopter. This system is used in over navigation of airplane.

Engineered Materials Arresting System (EMAS) is creating inhibition system by industrial materials. The term "industrial materials" means high resistant material with high energy absorption capability that are predictably compressed under the weight of airplane thereby applies resistance power on the wheel (Figure 2). As a result, the kinetic energy of the aircraft is reduced and finally stopped (Barsotti, 2012).

In general, foamed material follows the following hypothesis:

- Material with compression capacity without return to elastic mode
- Low nominal compression strength
- Negligible Poisson ratio
- Profile of ideal stepping function for the stress strain curve in compression mode
- High compression ability (high energy absorption)
- Negligible energy absorption in stretching

Figure 3 indicate stress strain curve in uni-axis compression test for ideal material.

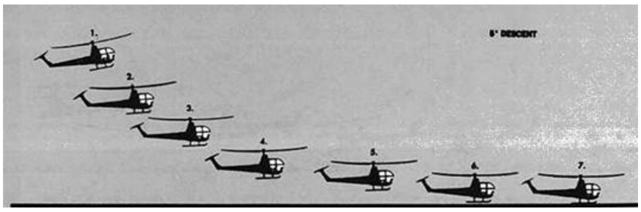

Figure 1. Running landing of helicopter

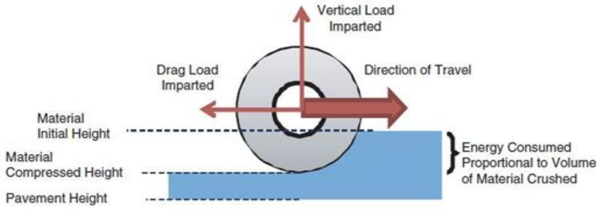

Figure 2. Physical operation of EMAS bed against the wheel power

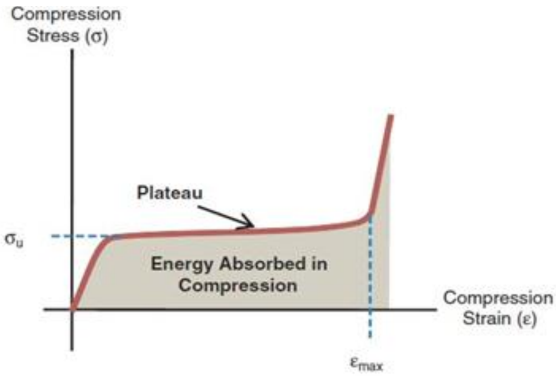

Figure 3. Stress-strain curve for ideal material

MATERIALS AND METHODS

Materials

In this study, glass foam and concrete foam materials are used as energy absorber materials. Glass foam is a compressive material with low density, used as inhibitory system. Glass foam has fine cellular texture close to each other that prevents the water penetration and makes it an excellent thermal insulation. Glass foam has properties of materials that provide good durability in nature and high chemical resistance. Generally they are made in blocks with different sizes and can be cut in different shapes according to the applications. Glass foam is applicable as separated or integrated blocks. Different experiments on glass foam indicate good performance of this material as energy absorbent material (Barsotti, 2012). Concrete foam or lightweight foamed concrete as materials with low density than usual concrete, can have more effective role in weight loss of buildings, especially in on-structural parts. Concrete along with foaming agent with animal protein base is called foam concrete. In addition to the benefits of ordinary concrete, this type of concrete has other properties such as low specific weight and high compressive strength. Regarding the air bubble production method, this concrete is divided to two types of gas and foam. In production of gaseous concrete, soft powder of aluminum is added to the mixture under special conditions, to produce bubbles of hydrogen in the concrete by chemical reaction of calcium hydroxide. Release of these bubbles causes the expansion of the mixture. In production of foam concrete, in contrast with gas concrete, air bubbles are produced by a foaming material and added to the concrete mixture. Foam concrete production technology is simpler than gas concrete production technology; it is also possible to build this type of concrete in construction workshops. The base materials in building foam concrete include cement, aggregates, water and foam from a foaming material. Foaming materials of the foam can be structurally classified in two classes including the materials based on animal protein foam and chemical protein foam (Amran et al., 2015). Characteristics of one glass foam and two types of concrete foam under use are provided in table 1 (Barsotti, 2012; Zhang et al., 2013).

To model the real situation and investigate the effect of stiffness of the path in stopping distance, the asphalt and concrete bands were used before energy absorbent bed, as representatives of flexible and rigid pavements with 50 and 200 m length. In most of the studies and modeling that has been done so far, asphalt and bitumen are modeled as elastic, but this modeling takes us away from reality. In this study, viscoelastic asphalt modeling was performed.

Abacus software studies viscoelastic behavior of materials in two main domains:

1. Time
2. Frequency

In the time domain, the large deformations of these materials and in the frequency domain the behavior of materials related to frequency are investigated.

There are four methods to define properties of viscoelastic materials in frequency domain:

- Determination of Prony series coefficients
- Creep Test Results
- Release Test Results
- Determination of frequency-dependent coefficients

Determination of frequency-dependent coefficients is classified as Formula and Tabular methods. According to previous studies in asphalt mixture behavior modeling, the use of Prony series coefficients has provided better results. Characteristics and Prony series coefficients for asphalt band is provided in tables 2 and 3.

Both the concrete and asphalt bands have 30 cm thickness, with rigid substrate layer. Elastic characteristics of the concrete band are provided in table 4. Plastic parameters of the concrete are ignored. As it is obvious from two tables, elastic module of rigid pavement is much more than flexible pavement. The converse of this mode is true for Poisson coefficient (Khani and Goli, 2016).

To simulate the real situation, characteristics of three helicopter with different weights and landing gear wheels are used. Based on the Helliport Audit Instructions, helicopters are divided into three categories in terms of the weight (Helliport Audit Instructions, 2013)

- Ultra-light helicopter: weight less than 600 kg
- Lightweight helicopter: weight between 600-3175 kg
- Heavy helicopter: weights more than 3175 kg

Selected helicopters of this study are all in heavy form and their characteristics are provided in table 5.

Methods

Abacus is series of highly capable modeling programs based on finite element method that can solve problems from simple linear analysis to the most complex non-linear modeling. This software has expanded set of elements that every geometry can be modeled virtually. It also has lots of engineering material models that provide high capability in modeling different materials with various properties and behaviors such as metals, plastics, polymers, composites, reinforced concrete, spring and fragile foams and also materials available on the earth such as soil and rock**.**

Lagrangian and Eulerian mesh network description

To observe non-linear behavior as well as making large or small deformations, the type of deformation and network (mesh) description is necessary. Mesh network description here refers to Lagrangian, Eulerian or Lagrange-Eulerian meshes. Spatial coordinates is represented by x, and are called Eulerian coordinates that indicate the position of nodes in space. Coordinates of materials (Lagrangian) are also indicated by x, which indicate the position of the points of materials at any time; at the beginning of analysis (t=0) these coordinates correspond spatial coordinates. With deformation of body under loading, Lagrangian and Eulerian points are separated from each other and take different values. In Eulerian mesh and at the external boundaries, the nodes remain on the boundary and do not move, while in Lagrange mesh and with deformation of other bodies, the nodes stay fixed on the boundaries and displace with materials.

Most of the problems cannot be analyzed by Lagrange meshes. In the cases of high deformation, Lagrangian elements are subsequently distorted because in Lagrangian method the elements move with the material. This is obvious especially in high ordered elements. Due to extreme distortion of elements, decamerian matrix of Jacobin will be negative at Goose points that result in stopping the calculations. As the name suggests, expression of ALE is an arbitrary combination of Lagrangian and Eulerian views. The term “arbitrary” indicates the fact that user combines these two views regarding how the mesh moves. But the meshes are always moved in a way to keep relatively regular shape of the elements (Zienkiewicz and Taylor, 1991).

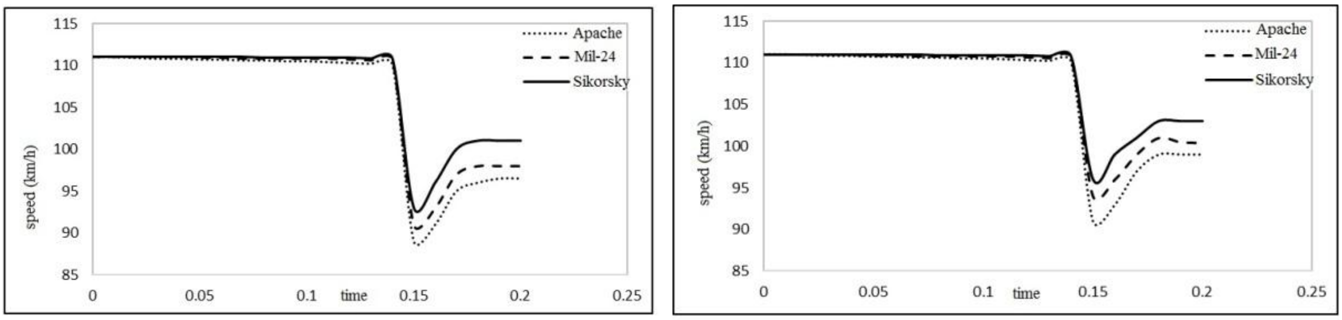

Figure 4. Velocity change diagrams at the crash time with a) asphalt band, b) concrete band

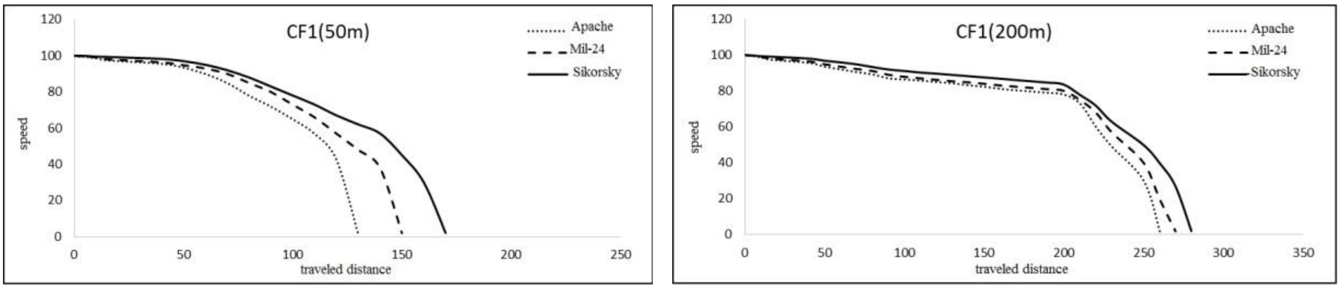

Figure 5. Speed change diagram along the path of 50 and 200 m asphalt band for CF1

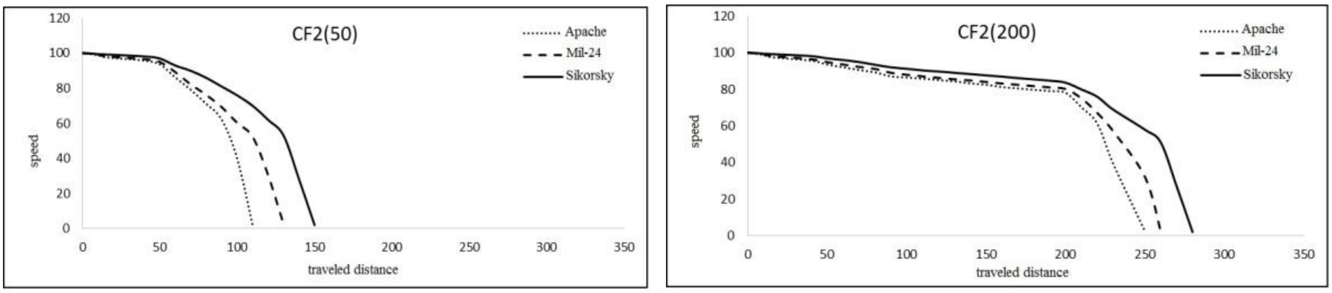

Figure 6. Speed change diagram along the path of 50 and 200 m asphalt band for CF2

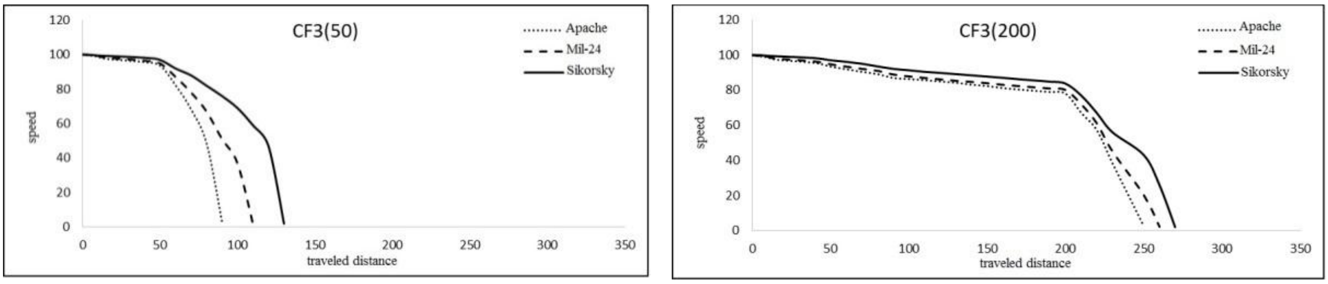

Figure 7. Speed change diagram along the path of 50 and 200 m asphalt band for CF3

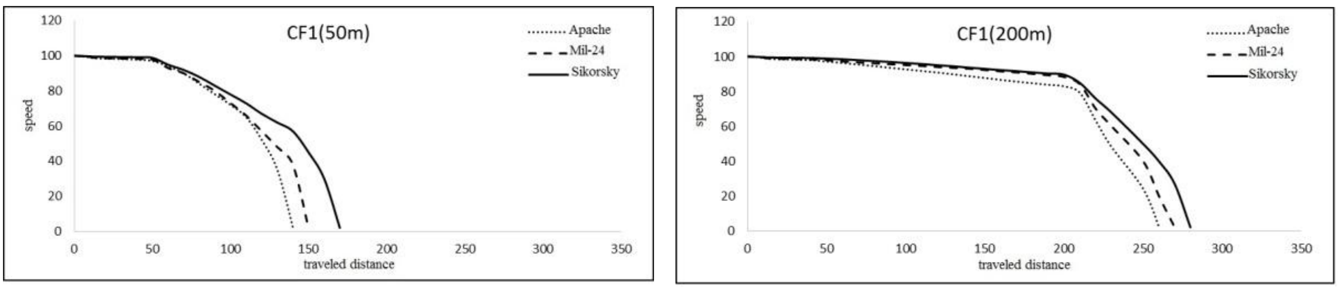

Figure 8. Speed change diagram along the path of 50 and 200 m concrete band for CF1

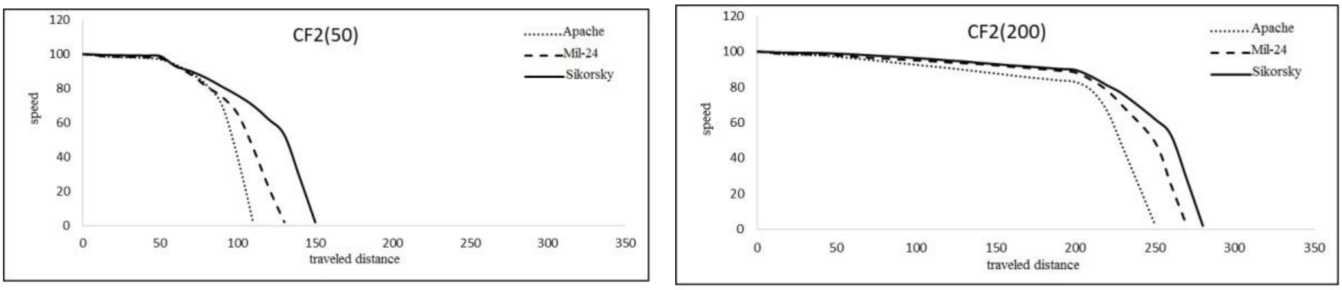

Figure 9. Speed change diagram along the path of 50 and 200 m concrete band for CF2

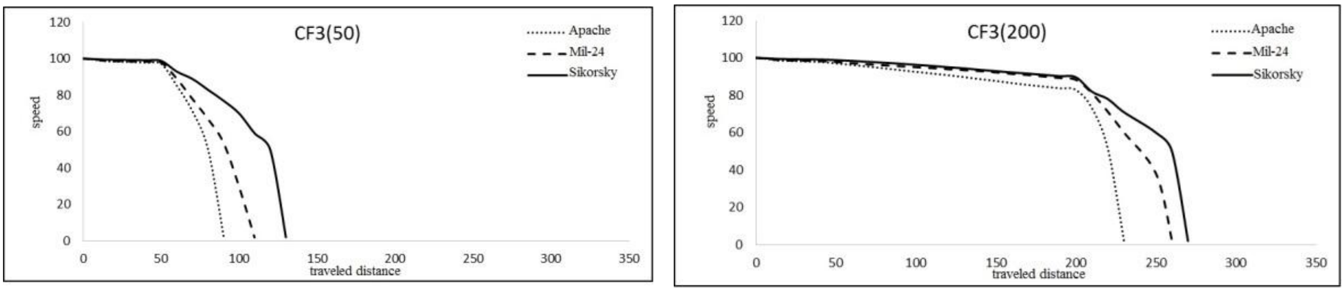

Figure 10. Speed change diagram along the path of 50 and 200 m concrete band for CF3

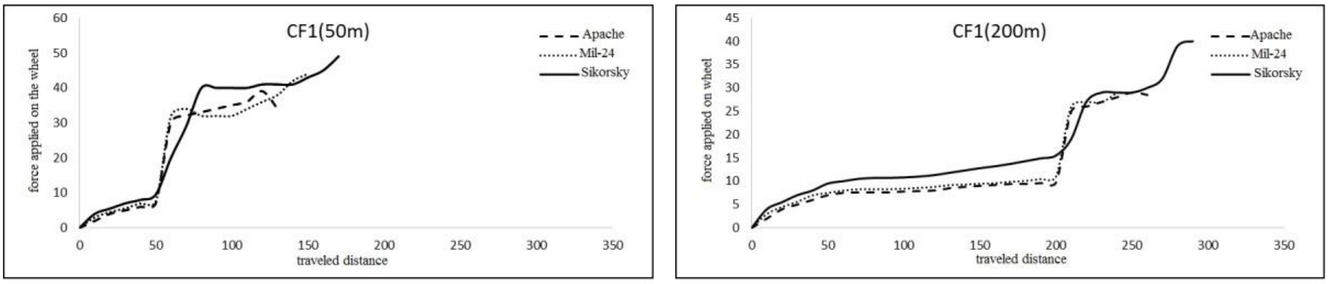

Figure 11. Force applied on wheel along the path of 50 and 200 m asphalt band for CF1

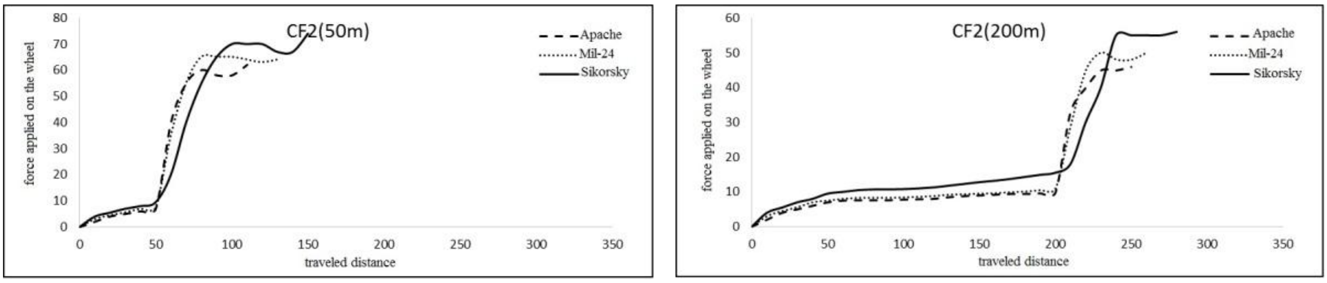

Figure 12. Force applied on wheel along the path of 50 and 200 m asphalt band for CF2

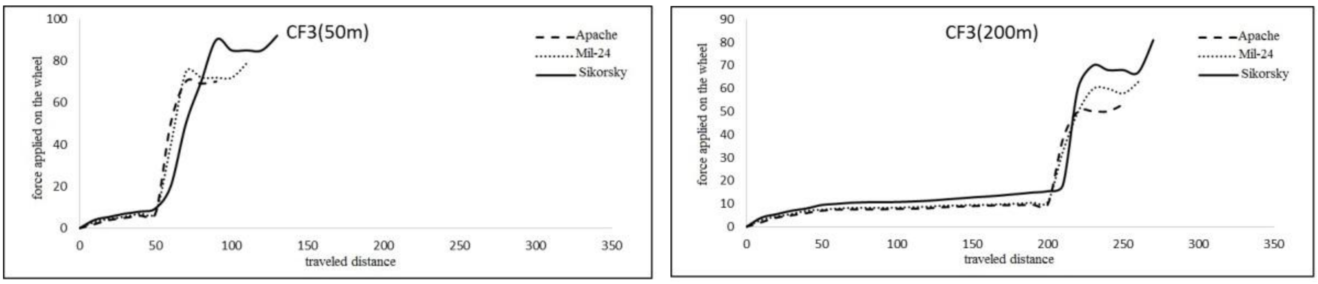

Figure 13. Force applied on wheel along the path of 50 and 200 m asphalt band for CF3

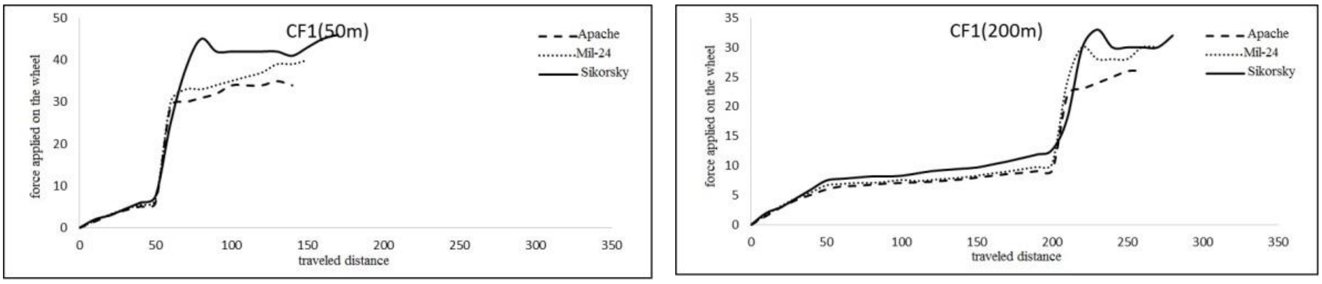

Figure 14. Force applied on wheel along the path of 50 and 200 m concrete band for CF1

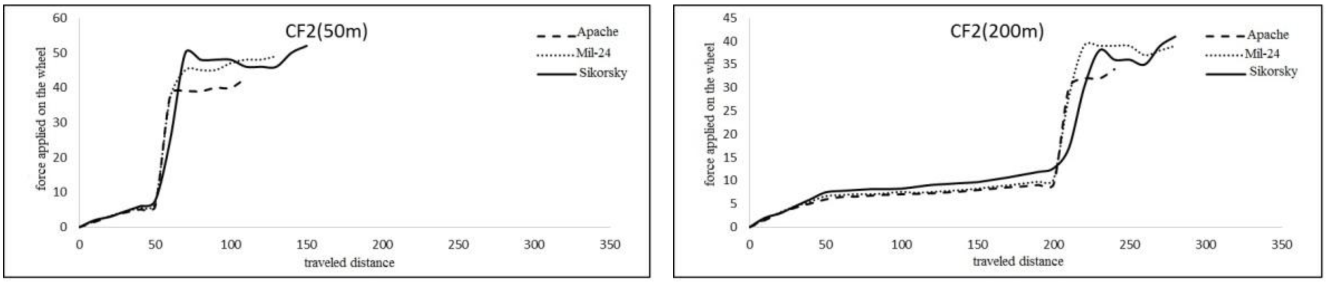

Figure 15. Force applied on wheel along the path of 50 and 200 m concrete band for CF2

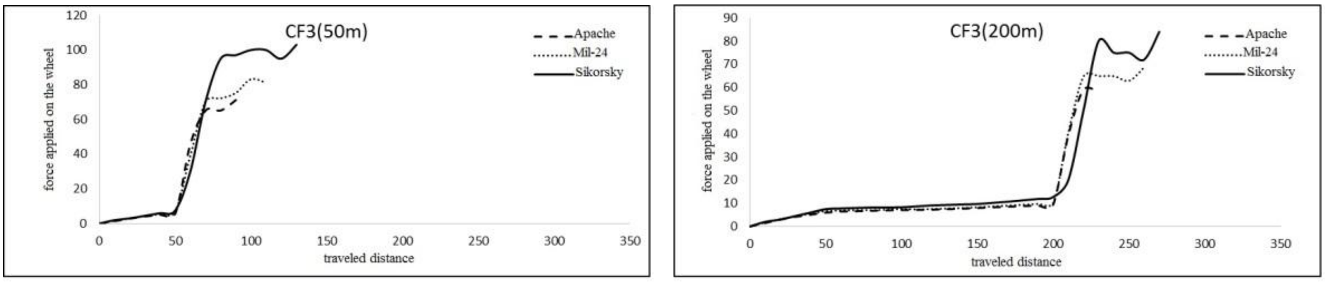

Figure 16. Force applied on wheel along the path of 50 and 200 m concrete band for CF3

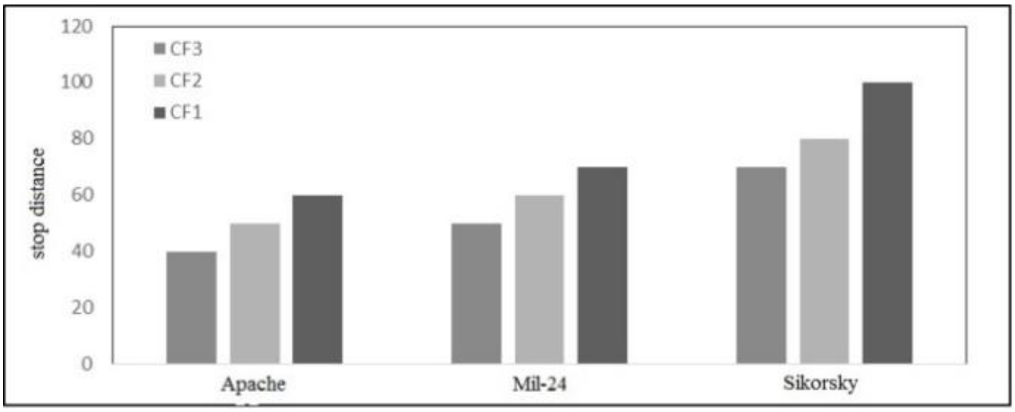

Figure 17. Stop distances of different helicopters and absorber material

Table 1. Characteristics of energy absorber material

Material	Abbreviation	Poisson coefficient	Elasticity module (Mpa)	Yield stress (Mpa)	Density (Kg/m^3)
Concrete foam 1	CF1	0	21.3	0.43	337
Concrete foam 2	CF2	0	14.5	0.35	302.4
Glass foam	CF3	0.05	2.52	0.302	650

Table 2. Elastic and viscoelastic characteristics of asphalt

Behavior of asphalt	Elasticity module (Mpa)	Poisson coefficient
Elastic	2760	0.35
Viscoelastic	4750	0.3

Table 3. Prony series coefficient of asphalt

No.	G_i	K_i	i^T
1	0.6499	0.6499	1E-2
2	0.2249	0.2249	1E-1
3	0.0852	0.0852	1
4	0.0246	0.0246	1E+1
5	0.0171	0.0171	1E+2
6	0.0018	0.0018	1E+3
7	0.0007	0.0007	1E+4

Table 4. Characteristics of concrete layer

Behavior of concrete	Elasticity Module	Poisson coefficient
Elastic	24090	0.15

Table 5. Properties required for modeling helicopter

Helicopter name	AH-64 Apache	Mil-24	Sikorsky CH-53
Net weight (Kg)	5165	8200	10740
Helicopter rate	Heavy	Heavy	Heavy
Loaded weight (Kg)	8000	11200	15227
Maximum speed (km/hr)	292	325	315
Flight peak (m)	6400	4500	5790

Table 6. Vertical tension applied on asphalt and concrete band at the crash moment

Type of band	Asphalt			Concrete		
Type of helicopter	Apache	Mil-24	Sikorsky	Apache	Mil-24	Sikorsky
Applied stress (Mpa)	3.78	6.98	9.64	4.96	8.59	11.31

RESULTS AND DISCUSIONS

In helicopter and airplane landing, the landing point as well as the amount of force applied on band is very important. Therefore, the pilot tries to minimize the applied force by better adjusting the angle and moving velocity. The landing band has special landing point for each airplane, where the airplane can only land on the designated area. Because providing adequate thickness for the entire band is not cost-effective, in areas where band bear more force, more thickness and resistance is considered for the band. In the following, to investigate the force applied by the selected helicopters on landing band, crash moment of the helicopter to the earth is simulated. The moving rate of helicopter on air during sliding landing maneuver is 60 knot (111.12 km/h and 30.87 m/s). The amount of stress applied on the band at the landing point is provided in table 6 for different helicopters. It is observed that the heavier helicopter naturally applies more tension to the bands. It is very difficult to withstand such a tension on the path not intended for landing, and the probability of path breakdown and overturning of helicopter is very high. Figures 4 and 5 indicate diagram of velocity changes versus time in seconds for two types of bands and different helicopters. It is observed that at the crash time at 0.14 s, velocity has steep slope and at continue of the path, helicopters travel at different speeds along the path. The amount of tension applied to concrete and asphalt substrates are different from each other. Due to approximate equality of the speed after crash of all three selected helicopters, the primary selected speed of the wheel at the beginning of the moving is equal for all three helicopters and equals to 27.77 m/s (100 km/h).

After simulation of wheel and energy absorption substrate, and applying design parameters, diagrams of speed changes versus the traveled distance are indicated on figures 5-10, and diagrams of horizontal force applied on the wheel versus traveled distance are indicated on figures 11-16. The wheel of the helicopter first travel on 50 and 200 m distances on asphalt and concrete bands, and then enter energy absorbent substrate.

CONCLUSION

Asphalt and concrete bands has no significant role on reduction of helicopter speed. With the helicopter passing through the bed, velocity reduction slope increases and helicopter stop in much shorter distance. As indicated in speed diagrams, heavier helicopters stop at longer distances and Apache lightweight helicopters achieve the speed of 2 km/s at much shorter distances. Energy absorber materials with lower elasticity module and yield stress have more ability to stop helicopters, while materials with higher elasticity module and yield stress can stop helicopter in longer distances. All in all, without considering the traveled distance in asphalt and concrete band, for Sikorsky heavy helicopter and the first energy absorber material with lower elasticity module, absorbent bed with 69 m length is required. Also, for Apache light weighted helicopters and first material, a 37 m length bed is required. Comparing 50 and 200 m diagrams, it can be concluded performance of band before energy absorbent bed is efficient only in landing. Therefore, it is possible to install several 100 m systems around the air bases and cities with high traffic of helicopters, to allow the pilot to approach the system as soon as possible and make running land in emergency cases. The problem that may appear is lack of control and rotation of helicopter to land in the direction of the band. To solve this problem, the energy absorber bed can be circularly designed to enable helicopter to land in all directions.

In speed diagrams at the last stopping distance, as well as in diagrams relating to the force applied to the jumper wheel, velocity change slope increases, which is due to sudden reduction of speed at the end of stop. When the wheel enters to energy absorber bed, the applied force suddenly increases. The faster the wheels velocity is, the less force is needed to crush energy absorber bed and to move forward. But at lower speeds, more resistance is needed against the wheel that increase the force applied on the wheel. Figure 17 compares the stop distance of helicopters and energy absorber beds for asphalt bed with 100 m of length.

After reviewing the graphs and comparing performance of energy absorber beds, it is concluded that glass foam material with Young module and lower yield stress, shows better performance. As noted before, preparation and implementation of glass foam is costly and is in conflict with the purposes and objectives of the project. Concrete foam is a material with components that can be easily available all over the Iran, and the Iranian labor force is dominant in its preparation and execution.

DECLARATIONS

Author's contribution

All authors contributed equally to this work.

Competing interests

The Authors declare that they have no competing interests.

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