10.48047/jocaaa.2024.32.01.50

Effect of Transverse Surface Roughness Patterns on the Performance of Short Bearings

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Abstract:

An effort was made to evaluate the performance of short bearings using magnetic fluid as a lubricant. Bearing surfaces are regarded as transversally rough. The roughness of the bearing surfaces is represented by a stochastic random variable with non-zero mean, variance, and skewness. The modified Reynolds equation is solved with appropriate boundary conditions to get the pressure distribution, which is then used to compute the load-bearing capacity. The Simpson's 1/3 rule is used for numerical integration. The findings are provided both visually and in tabular form. Magnetisation improves the bearing system's performance. It has also been discovered that roughness has a deleterious effect on the system. The study reveals that the negative impact of roughness may be mitigated by the positive effect of the magnetisation parameter. When constructing the bearing system, roughness must be taken into mind.

Keywords:

Short bearing, Transverse roughness, Magnetic fluid, Reynold's equation, Load carrying capacity.

1 Introduction

The slider bearing is the most basic type of hydraulic bearing and is used most of the time. In slider bearing, the film doesn't split up and stays together. These kinds of bearings are made to handle axial loads. Several books and study papers (Lord Rayleigh [1918], Archibald [1956]) give exact answers to Reynold's equation for slider bearings with different simple film shapes. In 1973, Prakash and Vij looked into the hydrodynamic lubrication of a plane inclined slider bearing using different shapes. They found that being porous made the friction and load-carrying capacity lower. Patel and Gupta [1983] expanded on the above study by Prakash and Vij [1973], adding the concept of slide velocity. They showed that the number of the slide parameter should be kept as low as possible to improve the performance of the bearing system.

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But bearing surfaces can get rough from wear, damage, or during production. To figure out what effect surface roughness has, Christensen [1969–70, 1971] came up with a random idea and applied an average film model to oiled surfaces that had striated roughness. Many researchers have used a random way to describe random roughness (Tzeng and Seibel [1967], Christensen and Tonder [1969a, 1969b, 1970]). Based on a general probability density function, Christensen and Tonder [1969a, 1969b, 1970] gave an all-encompassing general analysis for surface roughness. They did this by improving and changing the method of Tzeng and Seibel [1967]. These factors have prompted extensive research on the effects of surface roughness. Some examples are the work on the hydrodynamic journal bearing by Taranga et al. [1999], the hydrodynamic slider bearings by Christensen and Tonder [1971], and the squeeze film spherical bearing by Andharia et al. [2001]. A normal lube was used in all of these tests. It is well known that using magnetic fluid as a lube can change how well a bearing works. Agrawal [1986] looked at the design of Prakash and Vij [1973] with a magnetic fluid lubricant and found that it worked better than the design with a regular lubricant. Bhat and Deheri [1991] built on Agrawal [1986]'s work by looking at a magnetic fluid-based porous composite slider bearing. In 1995, Bhat and Deheri discussed a general porous slider bearing that has a magnetic fluid that forms a squeeze film. Patel and Deheri [2013] recently talked about the behaviour of a transversely rough magnetic fluid-based porous short bearing. Furthermore, Andharia et al. [2014] talked about how well a magnetic fluid-based short rough longitudinal bearing works.

It has been suggested that we look into how well a transversely rough short bearing works with a magnetic fluid lube, taking into account uneven roughness with a mean value that is not zero.

2. Analysis:

Fig. 1 depicts the bearing's shape and arrangement, which extends infinitely in the Z-direction.

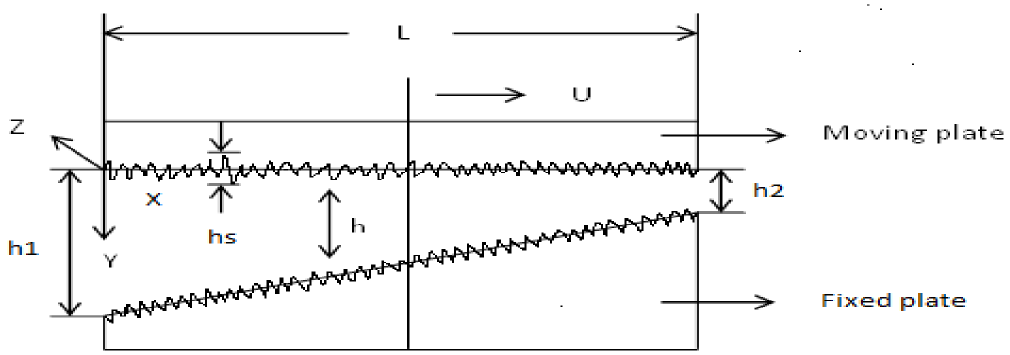

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Fig. 1 bearing's shape and arrangement

The slider moves with the uniform velocity U in X-direction. The length of bearing L and breadth B is in Z-direction, where $B << L$. The pressure gradient $\partial p/\partial z$ is very larger than pressure gradient $\partial p/\partial x$. The maximum and minimum film thicknesses are h_1 and h_2 respectively. The assumptions of usual hydrodynamic lubrication theory are taken into consideration in the development of the analysis.

The bearing surfaces are assumed to be transversely rough. The thickness h of the lubricant film is given by

$$h = \bar{h} + h_s \tag{1}$$

Where $\bar{h}$ is the mean film thickness and h_s is the deviation from the mean film thickness characterizing the random roughness of the bearing surfaces. h_s is considered to be stochastic in nature and governed by probability density function $f(h_s)$, $-c \leq h_s \leq c$, where c is the maximum deviation from the mean film thickness.

The mean α, the standard deviation σ and the measure of symmetry ε the random variable h_s are defined by the relationship :

$$\alpha = E\,(h_s) \tag{2}$$

$$\sigma^2 = E[(h_s - \alpha)^2] \tag{3}$$

and

$$\varepsilon = E[(h_s - \alpha)^3] \tag{4}$$

Where E is the expectancy operator defined by

$$E(R) = \int_{-c}^{c} f(h_s)dh_s \tag{5}$$

Wherein (Tzeng and Saibel [1967])

$$\mathrm{f}(h_s) = \frac{35}{32\mathrm{c}^7}(\mathrm{c}^2 - \mathrm{h}^2)^3, -\mathrm{c} \leq \mathrm{h} \leq \mathrm{c}$$

$$= 0, \qquad \text{elsewhere} \tag{6}$$

It is easily observed that α, σ and ε are independent of x.

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The magnetic field is oblique to the stator as in Agrawal [1986]. Following discussions carried out by Prajapati [1995] regarding the effect of various forms of magnitude of magnetic field is expressed as

$$M^2 = KB^2 \left\{ \left(\frac{1}{2} + \frac{z}{B}\right) \, sin\left(\frac{1}{2} - \frac{z}{B}\right) + \left(\frac{1}{2} - \frac{z}{B}\right) \, sin\left(\frac{1}{2} + \frac{z}{B}\right) \right\} \tag{7}$$

Where B is the breadth of bearing and K is a suitably chosen constant from dimensionless point of view (Bhat and Deheri [1995]).

The lubricant film is considered to be isoviscous and incompressible and the flow is laminar. With the usual assumption of hydrodynamic lubrication, the modified Reynold's equation for film pressure is given by

$$h^3 \frac{d^2}{dz^2}\left(p - \frac{\mu_0 \bar{\mu} M^2}{2}\right) = 6\mu U \frac{dh}{dx} \tag{8}$$

Applying averaging process, the modified Reynold's equation for film pressure (Bhat [2003], Prajapati [1995], Deheri, Andharia and Patel [2005]) is given by

$$\frac{d^2}{dz^2}\left(p - \frac{\mu_0 \bar{\mu} M^2}{2}\right) = \frac{6\mu U}{g(h)} \frac{dh}{dx} \tag{9}$$

Where $h = h_2 \left\{1 + m\left(1 - \frac{x}{L}\right)\right\}$

$$g(h) = h^3 + 3h^2\alpha + 3h(\alpha^2 + \sigma^2) + (\alpha^3 + 3\sigma^2\alpha + \varepsilon)$$

while μ_0 is the magnetic susceptibility, $\bar{\mu}$ is the free space permeability and μ is the lubricant viscosity.

The associated boundary conditions are

$$p = 0; \; z = \pm\frac{B}{2} \text{ and } \frac{dp}{dz} = 0; \; z = 0 \tag{10}$$

By integrating Eq. (8) with respect to z

$$\frac{d}{dz}\left(p - \frac{\mu_0 \bar{\mu} M^2}{2}\right) = \frac{6\mu U}{g(h)} \, z \, \frac{dh}{dx} + Q_1 \tag{11}$$

Where Q_1 is a constant.

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At $z = 0; \ \frac{dp}{dz} = 0; \ \frac{d}{dz}(M^2) = 0$

and Q_1 = 0

Again by integrating Eq. (10) with respect to z

$$p - \frac{\mu_0 \bar{\mu} M^2}{2} = \frac{3\mu U}{g(h)} z^2 \frac{dh}{dx} + Q_2 \tag{12}$$

Where Q_2 is a constant.

At $z = \pm\frac{B}{2}; \ p = 0; \ M^2 = 0$ and $Q_2 = \frac{-3\mu U}{g(h)} \frac{B^2}{4} \frac{dh}{dx}$

By Eq. (11) and introducing the dimensionless quantities

$$Z = \frac{z}{B}, X = \frac{x}{L}, m = \frac{h_1 - h_2}{h_2}, \mu^* = \frac{h_2^3 K \mu_0 \bar{\mu}}{\mu U}, P = \frac{h_2^3}{\mu U B^2}, \bar{\alpha} = \frac{\alpha}{h_2}, \bar{\sigma} = \frac{\sigma}{h_2}, \bar{\varepsilon} = \frac{\varepsilon}{h_2}, \ \bar{L} = \frac{L}{h_2} \tag{13}$$

The pressure distribution in dimensionless form

$$P = \frac{\mu^*}{2}\left[\left(\frac{1}{2} + Z\right) sin\left(\frac{1}{2} - Z\right) + \left(\frac{1}{2} - Z\right) sin\left(\frac{1}{2} + Z\right)\right] + \frac{3m}{\bar{L}}\left(\frac{1}{4} - Z^2\right)\left[\frac{1}{A_1^3 + 3\bar{\alpha}A_1^2 + 3(\bar{\alpha}^2 + \bar{\sigma}^2)A_1 + (\bar{\alpha}^3 + 3\bar{\sigma}^2\bar{\alpha} + \bar{\varepsilon})}\right] \tag{14}$$

Where $A_1 = \{1 + m(1 - X)\}$

The load carrying capacity of bearing

$$w = \int_{\frac{-B}{2}}^{\frac{B}{2}} \int_0^1 p(x, z) \ dx \ dz \tag{15}$$

Dimensionless load carrying capacity is obtained as

$$W = \frac{\bar{L}}{\bar{B}} \int_{\frac{-1}{2}}^{\frac{1}{2}} \int_0^1 P \ dX \ dZ \tag{16}$$

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3. Results and Discussions:

It is seen that Eq. (14) represents the expression for the dimensionless pressure distribution and Eq. (16) determined the load carrying capacity in dimensionless form. These performance characteristics depend on various parameters such as magnetization parameter μ^*, length ratio L/h_2, breadth ratio B/h_2, aspect ratio m, roughness parameters σ, α and Ɛ etc. Eq. (16) is numerically integrated using Simpson's 1/3 rule for different values of μ^*, σ, α and Ɛ. The results are presented graphically in Figs. (2) – (9) and also numerically in table form as Table (1) – (13).

Figs. (2) and (3) represent the variation of load carrying capacity with respect to magnetization parameter μ^* for various values of L/h_2 and B/h_2 respectively. These figures show that the load carrying capacity increases significantly due to magnetic fluid lubricant.

Fig. (4) shows the effect of L/h_2 on dimensionless load carrying capacity for various values of B/h_2. From this figure it is suggest that the load carrying capacity increases considerably due to L/h_2.

Fig. (5) suggests the effect of B/h_2 on dimensionless load carrying capacity for various values of σ/h_2. From this figure it is clear that the load carrying capacity decreases sharply due to B/h_2.

Fig. (6) – (8) present the profile of the load carrying capacity with respect to σ/h_2 for various values of m, α/h_2 and ε/h_2. These figures suggest that the effect of standard deviation is almost negligible so far as the dimensionless load carrying capacity is concerned

Fig. (9) shows the variation of load carrying capacity with respect to α/h_2 and ε/h_2. From the figure it is clearly shown that load carrying capacity decreases marginally due to α/h_2.

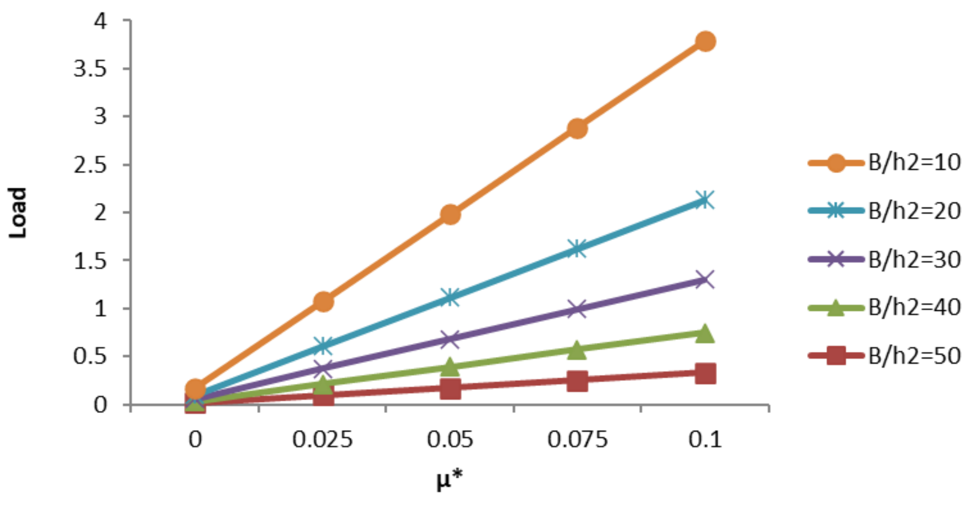

Fig. 2 Variation of load carrying capacity with respect to μ^* and L/h_2

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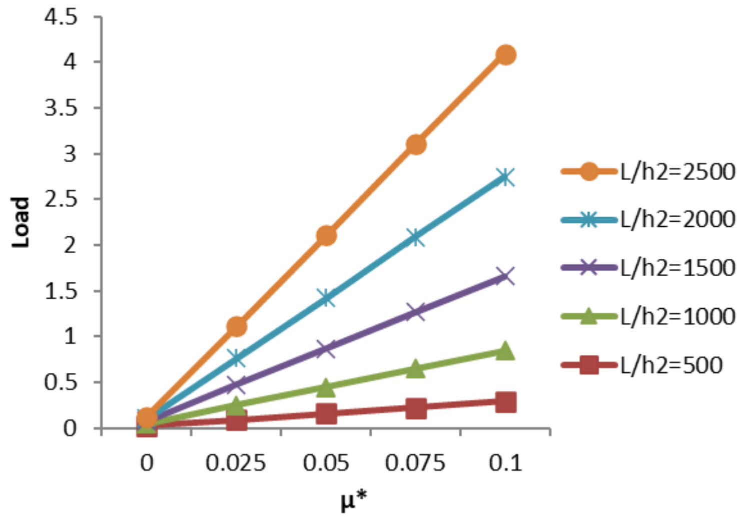

Fig. 3 Variation of load carrying capacity with respect to μ* and B/h_2

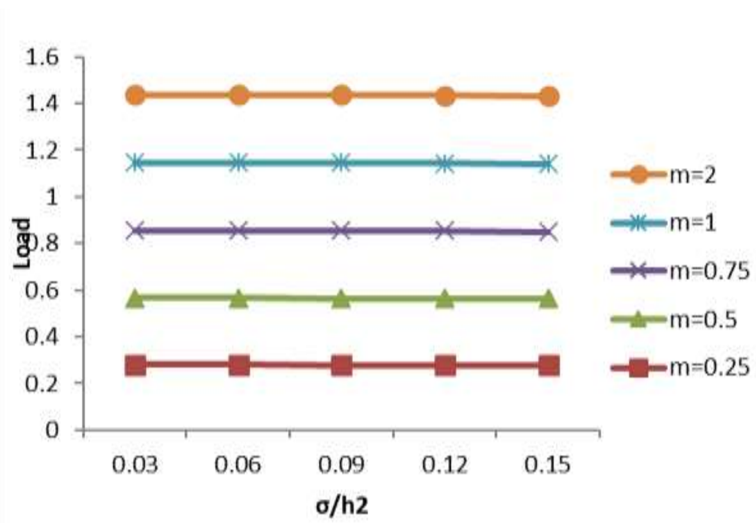

Fig. 4 Variation of load carrying capacity with respect to L/h_2 and B/h_2

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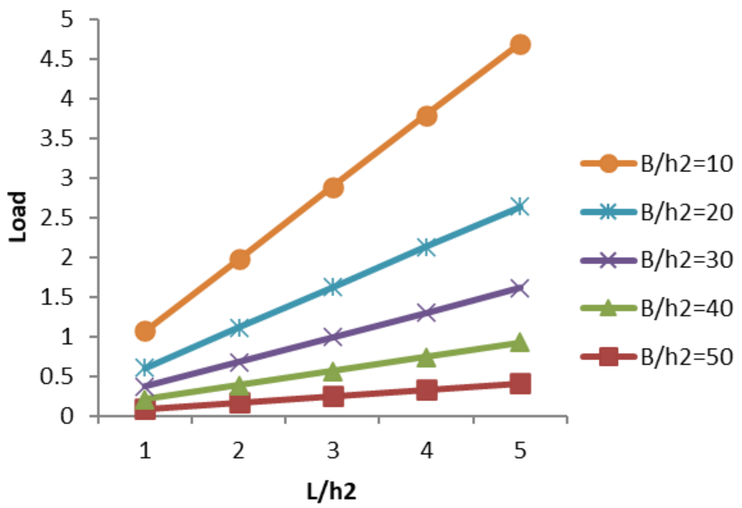

Fig.5 Variation of load carrying capacity with respect to B/h_2 and σ/h_2

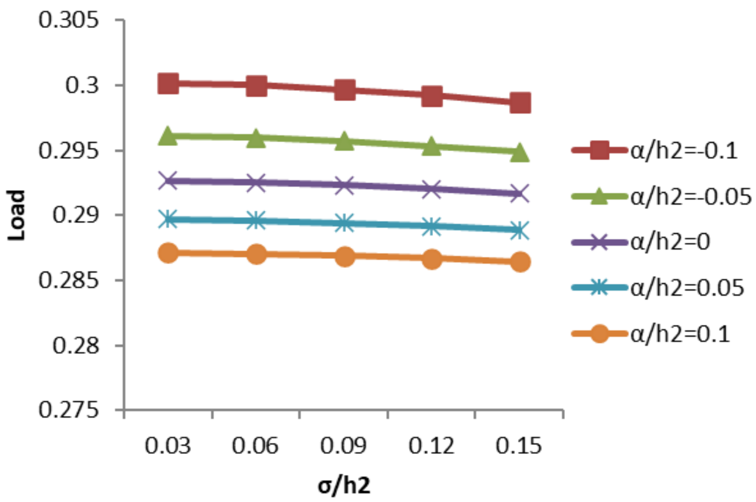

Fig. 6 Variation of load carrying capacity with respect to $\sigma/h_2$and m

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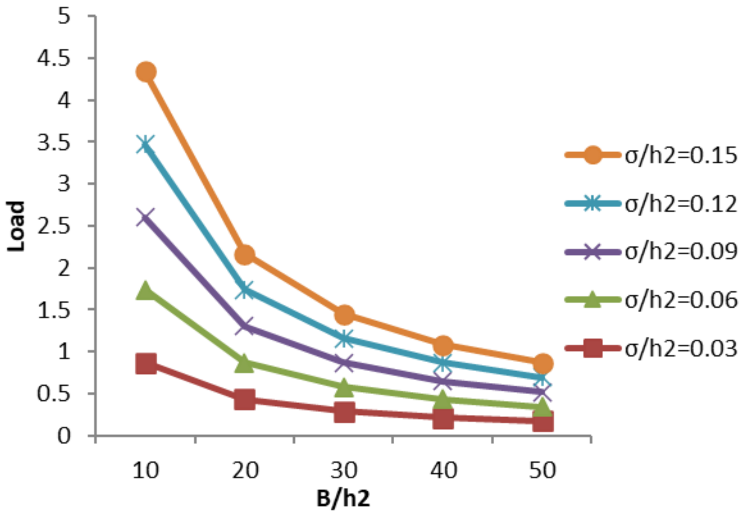

Fig. 7 Variation of load carrying capacity with respect to σ/h_2 and α/h_2

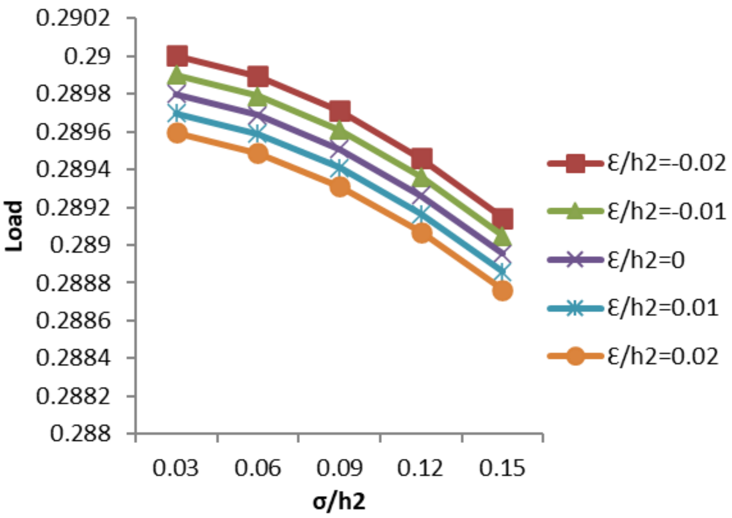

Fig. 8 Variation of load carrying capacity with respect to σ/h_2 and $\mathcal{E}/h_2$

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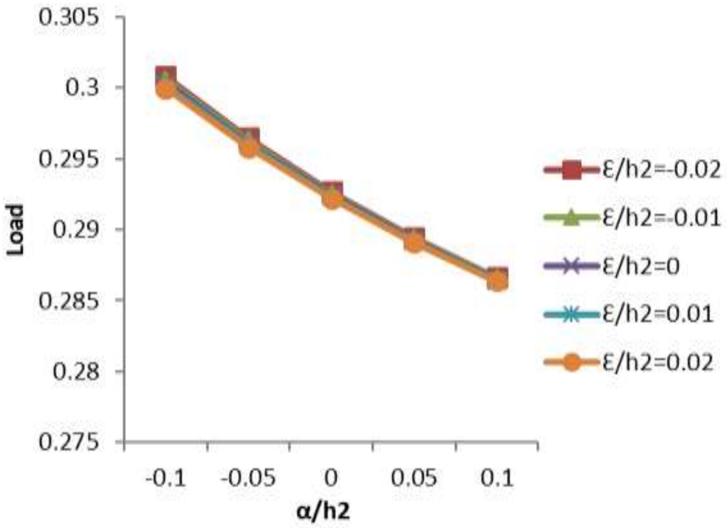

Fig. 9 Variation of load carrying capacity with respect to $\alpha/h_2$and $\mathcal{E}/h_2$

Tables 1 – 4 show the effect of μ^* on the dimensionless load carrying capacity for various values of aspect ratio m, σ/h_2, α/h_2 and $\mathcal{E}/h_2$ respectively. From these tables it is clear that the load carrying capacity increases sharply due to magnetization and the effect of aspect ratio m, σ/h_2, α/h_2 and $\mathcal{E}/h_2$ is negligible with respect to magnetization parameter μ^*.

Tables 5 – 8 present the effect of L/h_2 on the dimensionless load carrying capacity for various values of aspect ratio m, σ/h_2, α/h_2 and $\mathcal{E}/h_2$respectively. It is noticed that the dimensionless load carrying capacity increases significantly due to L/h_2.

Table 9 – 11 suggest the variation of load carrying capacity with respect to $B/h_2$and aspect ratio m, α/h_2 and $\mathcal{E}/h_2$ respectively. It is shown that the effect of aspect ratio m, α/h_2 and $\mathcal{E}/h_2$ on load carrying capacity decreases with increasing values of B/h_2.

Table 12 and 13 represent the effect of α/h_2 and $\mathcal{E}/h_2$ on the dimensionless load carrying capacity for various values of m. Furthermore, the aspect ratio has a strong positive effect in the sense that the load capacity increases sharply.

Table 1 Variation of load carrying capacity with respect to μ^* and m

m	Load				
	μ^* = 0	μ^* = 0.025	μ^* = 0.05	μ^* = 0.075	μ^* = 0.1
0.25	0.014383	0.146492	0.278600	0.410708	0.542817
0.50	0.021405	0.153513	0.285621	0.417730	0.549838
0.75	0.024949	0.157057	0.289165	0.421274	0.553382
1.00	0.026662	0.158770	0.290879	0.422987	0.555095
2.00	0.026528	0.158636	0.290744	0.422853	0.554961

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Table 2 Variation of load carrying capacity with respect to μ^* and σ/h_2

σ/h_2	Load				
	μ^* = 0	μ^* = 0.025	μ^* = 0.05	μ^* = 0.075	μ^* = 0.1
0.03	0.025479	0.157588	0.289696	0.421804	0.553913
0.06	0.025371	0.157480	0.289588	0.421696	0.553805
0.09	0.025193	0.157302	0.289410	0.421518	0.553627
0.12	0.024949	0.157057	0.289165	0.421274	0.553382
0.15	0.024642	0.156750	0.288858	0.420967	0.553075

Table 3 Variation of load carrying capacity with respect to μ^* and α/h_2

α/h_2	Load				
	μ^* = 0	μ^* = 0.025	μ^* = 0.05	μ^* = 0.075	μ^* = 0.1
-0.10	0.035013	0.167121	0.299230	0.431338	0.563446
-0.05	0.031133	0.163242	0.295350	0.427458	0.559567
0.00	0.027811	0.159919	0.292028	0.424136	0.556244
0.05	0.024949	0.157057	0.289165	0.421274	0.553382
0.10	0.022469	0.154578	0.286686	0.418794	0.550903

Table 4 Variation of load carrying capacity with respect to μ^* and ε/h_2

ε/h_2	Load				
	μ^* = 0	μ^* = 0.025	μ^* = 0.05	μ^* = 0.075	μ^* = 0.1
-0.02	0.025243	0.157351	0.289459	0.421568	0.553676
-0.01	0.025144	0.157252	0.289361	0.421469	0.553577
0.00	0.025046	0.157154	0.289263	0.421371	0.553479
0.01	0.024949	0.157057	0.289165	0.421274	0.553382
0.02	0.024853	0.156961	0.289069	0.421178	0.553286

Table 5 Variation of load carrying capacity with respect to $L/h_2$and m

m	Load				
	L/h_2 = 500	L/h_2= 1000	L/h_2= 1500	L/h_2= 2000	L/h_2= 2500
0.25	0.146492	0.278600	0.410708	0.542817	0.674925
0.50	0.153513	0.285621	0.417730	0.549838	0.681946
0.75	0.157057	0.289165	0.421274	0.553382	0.685490
1.00	0.158770	0.290879	0.422987	0.555095	0.687204
2.00	0.158636	0.290744	0.422853	0.554961	0.687069

Table 6 Variation of load carrying capacity with respect to L/h_2 and σ/h_2

σ/h_2	Load				
	L/h_2 = 500	L/h_2= 1000	L/h_2= 1500	L/h_2= 2000	L/h_2= 2500

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0.03	0.157588	0.289696	0.421804	0.553913	0.686021
0.06	0.157480	0.289588	0.424696	0.553805	0.685913
0.09	0.157302	0.289410	0.421518	0.553627	0.685735
0.12	0.157057	0.289165	0.421274	0.553382	0.685490
0.15	0.156750	0.288858	0.420967	0.553075	0.685183

Table 7 Variation of load carrying capacity with respect to L/h_2 and α/h_2

α/h_2	Load				
	L/h_2 = 500	L/h_2= 1000	L/h_2= 1500	L/h_2= 2000	L/h_2= 2500
-0.10	0.167121	0.299230	0.431338	0.563446	0.695555
-0.05	0.163242	0.295350	0.427458	0.559567	0.691675
0.00	0.159919	0.292028	0.424136	0.556244	0.688353
0.05	0.157057	0.289165	0.421274	0.553382	0.685490
0.10	0.154578	0.286686	0.418794	0.550903	0.683011

Table 8 Variation of load carrying capacity with respect to $L/h_2$and $\mathcal{E}/h_2$

$\mathcal{E}/h_2$	Load				
	L/h_2 = 500	L/h_2= 1000	L/h_2= 1500	L/h_2= 2000	L/h_2= 2500
-0.02	0.157351	0.289459	0.421568	0.553676	0.685784
-0.01	0.157252	0.289361	0.421469	0.553577	0.685686
0.00	0.157154	0.289263	0.421371	0.553479	0.685588
0.01	0.157057	0.289165	0.421274	0.553382	0.685490
0.02	0.156961	0.289069	0.421178	0.553286	0.685394

Table 9 Variation of load carrying capacity with respect to B/h_2 and m

m	Load				
	B/h_2 = 10	B/h_2= 20	B/h_2= 30	B/h_2= 40	B/h_2= 50
0.25	0.835800	0.417900	0.278600	0.208950	0.167160
0.50	0.856864	0.428432	0.285621	0.214216	0.171373
0.75	0.867496	0.433748	0.289165	0.216874	0.173499
1.00	0.872636	0.436318	0.290879	0.218159	0.174527
2.00	0.872233	0.436117	0.290744	0.218058	0.174447

Table 10 Variation of load carrying capacity with respect to $B/h_2$and α/h_2

α/h_2	Load				
	B/h_2 = 10	B/h_2= 20	B/h_2= 30	B/h_2= 40	B/h_2= 50
-0.10	0.897689	0.448844	0.299230	0.224422	0.179538
-0.05	0.886050	0.443025	0.295350	0.221513	0.177210

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0.00	0.876083	0.438042	0.292028	0.219021	0.175217
0.05	0.867496	0.433748	0.289165	0.216874	0.173499
0.10	0.860058	0.430029	0.286686	0.215014	0.172012

Table 11 Variation of load carrying capacity with respect to B/h_2 and $\mathcal{E}/h_2$

$\mathcal{E}/h_2$	Load				
	B/h_2 = 10	B/h_2= 20	B/h_2= 30	B/h_2= 40	B/h_2= 50
-0.02	0.868378	0.434189	0.289459	0.217094	0.173676
-0.01	0.868082	0.434041	0.289361	0.217020	0.173616
0.00	0.867788	0.433894	0.289263	0.216947	0.173558
0.01	0.867496	0.433748	0.289165	0.216874	0.173499
0.02	0.867208	0.433604	0.289069	0.216802	0.173442

Table 12 Variation of load carrying capacity with respect to α/h_2 and m

m	Load				
	α/h_2 = -0.1	α/h_2= -0.05	α/h_2= 0	α/h_2= 0.05	α/h_2= 0.1
0.25	0.285585	0.282836	0.280537	0.278600	0.276956
0.50	0.294992	0.291348	0.288258	0.285621	0.283357
0.75	0.299230	0.295350	0.292028	0.289165	0.286686
1.00	0.300922	0.297077	0.293759	0.290879	0.288366
2.00	0.298844	0.295806	0.293123	0.290744	0.288627

Table 13 Variation of load carrying capacity with respect to $\mathcal{E}/h_2$and m

m	Load				
	$\mathcal{E}/h_2$ = -0.02	$\mathcal{E}/h_2$= -0.01	$\mathcal{E}/h_2$= 0	$\mathcal{E}/h_2$= 0.01	$\mathcal{E}/h_2$= 0.02
0.25	0.278860	0.278772	0.278686	0.278600	0.278516
0.50	0.285926	0.285823	0.285722	0.285621	0.285522
0.75	0.289459	0.289361	0.289263	0.289165	0.289069
1.00	0.291147	0.291057	0.290967	0.290879	0.290791
2.00	0.290906	0.290852	0.290798	0.290744	0.290691

4. Conclusion:

This investigation suggests that the effect of roughness parameters is negligible. This conditional effect increases with the larger values of σ/h_2, α/h_2 and $\mathcal{E}/h_2$. The results show that the negative effect of B/h_2, σ/h_2, α/h_2 and $\mathcal{E}/h_2$ can be reduced to a larger extent by

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the positive effect of magnetization parameter μ^* and L/h_2, choosing a suitable values of aspect ratio m.

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