Effect of different parameters on coefficient of friction between rigid pavement and subbase layer

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Abstract. The coefficient of friction is a quantity indicates the ratio of frictional force between objects. As pavement experiences thermal changes, it may slide against supporting subbase resistance. This resistance must be determined in order for pavement to perform as anticipated. Cracking of concrete does not occur if the pavement is jointed. In the joint plain concrete pavements, a separator layer is installed between the subbase and the plate to smooth the interface. A smooth surface shows less resistance to the concrete's displacement caused by temperature difference. Two stages of the push-off test were conducted for subbase conditions (smooth and rough). Friction properties among the concrete and subbase were investigated based on the friction test results. The results show the parameters impacting the maximum coefficient of friction and displacement (interface condition, movement rate, thickness) respectively for friction and (movement rate, interface condition, thickness) for displacement. In conclusion, the frictional force rises significantly until the applied force reaches the stable condition. This force is affected by interface condition, which has the most significant impact, followed by movement rate and thickness. Changing conditions from smoother to rougher interface leads to raising maximum coefficient of friction regardless of changing slab thickness or movement rate.

Keywords: joint plain concrete pavement; push-off test; subbase; slab; displacement; friction

1. Introduction:
The classical perspective of friction has described it as frictional resistance. It can be obtained by finding the laterally applied force \((P)\) that applies to the object's weight \((W)\), which is equal to or less than the frictional resistance. \((N)\) represent the reactions to these forces as illustrated in figure 1. The frictional resistance increases as long as an applied force increases, and they stay in an equilibrium state until the maximum value of laterally applied force. This maximal value is generally mentioned as the static friction coefficient, which can be obtained by dividing \((P)\) by \((W)\). Once exceeding the maximum frictional resistance force, the block begins to move. The frictional resistance drops to its
The maximum dynamic frictional resistance. The dynamic friction factor will permanently be less than the static friction factor. They could be calculated using a similar method [10]. The features of these coefficients seem to be: applied force independently, independent of the area of the contacting surfaces, and dependent on the nature of the surfaces in contact and the exact condition of the surfaces [4].

When a concrete plate contract because of a decrease of temperature, humidity decline or concrete creeping, the frictional forces generated. Once that happen, the interface's friction resists the movements. Movement resistance contributes to producing direct tensile stress in the concrete.

The slab's movements rise from zero at the centre to maximum at the edges. The tensile stresses formed within the plate by the restraint decline from a maximum at the centre to zero at the free edges. Since the movements frictional resistance grow from the slab ends. The higher restraint, lead to higher generated tensile stresses along whole length of concrete plate. Those tensile stresses are essential since they could be additional to that tensile stresses caused by road traffic and restrained thermic wrapping. To such a degree that the plate would crack [10]. As concrete seems to have a weak tensile strength, the production of even minor tensile stresses due to shrinkage can often lead to cracking inside the restrained concrete components. Cracking decreases the load-bearing capacity of the concrete parts, results in the deterioration of the steel reinforcement, raises the risk of alkali-silica reactions and sulfate attacks, and causes other durability conflicts leading to the increased cost of maintenance and decreased service life. The algorithm's main parts have been widely described in [8].

Many researchers examined the interlayer friction properties between the concrete pavement and the sub-base by performed push-off tests. The method implemented in the previous push-off test has been mainly for calculating the concrete test slabs' displacements throughout the application of the horizontal forces which inducting the movements. [10] observed the sliding plane's direction. The sliding plane has been noticed at the slab-base interface in loose, unbound base situations, such as loam, clay, and granular base. [10] conclude that the slip plane had not existed at the slab-subbase interface but down in the sub-base. This significant observation shows that frictional resistance is not based on the frictional features between the pavement and its subbase. However, it is dependent on the material strength conditions of even the subbase. In reality, any piece of concrete cut and separated from the slab for the push-off machinery had a subbase added to its bottom, except untreated clay.

There have been two typical coefficients of friction (µ) displacement relationship shapes noticed, as can be seen in figure 2. In the two cases, µ is increased in a parabolic pattern to the point of the slab movement reaching preliminary displacement. Type A has been noticed in the soft and loose subbases, while Type B has been noticed in the stiff and dense sub-bases at the first slab movement cycle. However, the Type B shape tends to change towards type A after a few slab movement intervals [6].
observed daily variations for temperature gradient in the depth of the pavement. Positive and negative non-linear temperature variations have been taken over the concrete plate depth. The gradients were obtained on two concrete laboratory samples using temperature tests on concrete model slabs. The temperature difference is roughly uniform at the underside of the concrete. The seasonal temperature change was formulated as a constant temperature rise or decline.

[5]; [7] have noticed that varying µ-displacement relationship from the first slab displacement cycle to the second one is considerable. However, varying µ-displacement relationship with several cycles has the tendency of being insignificant following the third to fourth slab displacement cycle. Smoothening the sliding plane has been considered as one of the potential causes for decreased µ and increased preliminary displacement with a number of the slab movement cycles.

The impacts of the thickness of the slab on µ-displacement correlation, which has been investigated in the earlier study [10], have noticed that subbases of granular or sand type have little impact on the development of µ when the thickness of the slab differs.

2. The aim and objectives for this study
The main aim of this work is to calculate the coefficient of friction and its relationship with conditions affecting concrete pavement by using local materials. To catch the aim of the study, the push-off test has carried out with three variables (rate movement, slab thickness, interface condition). This has been the objective of various similar studies in the last decades.

3. Materials Used

3.1. Concrete
Concrete with a compressive strength of (31 MPa in 28 days) was used. The proportions of the mixture (i.e., the cement, sand, and gravel) adopted for the concrete slabs were (1:2.2:3.2) based on the properties described by [3], as shown in table 1, which achieves a compressive strength of more than 30 MPa. The mix proportions are illustrated in table 1 with a maximum aggregate size of 19 mm, both coarse and fine aggregate match gradation according to [9].

3.2. Sub-base
Type A sub-base layer was used and compacted, (200 mm) thickness subbase granular material (SGM), which satisfies the specification grading accordance with [9] and limits of type A.

3.3. Polyethylene sheet
A (125µm) thick polyethylene nylon layer was placed under the slabs for smooth friction.

Table 1. Mixture Proportion of Concrete Slabs.

| Slump (mm) | Water/Cement ratio (%) | Fine/Aggregate (%) | Water (L) | Cement (Kg) | Fine (Kg) | Coarse (Kg) | Unit(kg/m³) |
|------------|------------------------|--------------------|-----------|-------------|-----------|-------------|-------------|
| 60         | 40                     | 40                 | 140       | 350         | 775       | 1135        |             |

4. Push-off Test
The push-off test was conducted at the Materials Lab in College of Engineering/ Civil Engineering Department of Mustansiriyah University; the field test has been carried out in a testing box inside (4.1 m) long (2.1 m) width. The subbase layer in the box has been granular materials laid in the box's entire area, as shown in the 3-dimensional diagram of the testing room figure 3. The push-off test has been conducted by concrete slabs, which have been put on the top of various interface types. Two different interface conditions have been given; the testing slab has been directly cast on SGM.
One layer of a polyethylene sheet has been located between the test slab and the subbase layer. The temperature during the test was approximately (16.9 - 28.9°C). Various studies have used the push-off test in the last decades, but only one local study was conducted by [2].

As illustrated in figure 3, three concrete slabs of (1000*500 mm) for length and width, respectively with three different thicknesses (100, 150 and 200 mm) were (concrete slab directly cast on SGM, and a polyethylene sheet placed between concrete slab and subbase layer). The experiments were carried out for the rough interface (with no polyethylene sheet) and smooth interface with polyethylene sheet laid between slab and subbase layer. The series of various parameters that have been taken under consideration in the experiential program are listed in table 2. A total of eighteen slabs have been cast. Every six slabs represent series were included three slabs with a smooth interface and three slabs with a rough interface of the same thickness. The current study used one type of subbase and two interface conditions.

![Figure 3. 3-dimensional diagram of the testing room.](image)

**Table 2. Details of Experimental Series**

| Subbase Type                | Slabs Number | Type of Interfaces | Thickness of Slab (mm) | Codes of Slabs       |
|-----------------------------|--------------|--------------------|------------------------|----------------------|
| 200mm thick. Granular Materials | 3            | Smooth             | 100                    | S10a6,S10a9,S10a12   |
|                             | 3            | Rough              | 100                    | S10b6,S10b9,S10b12   |
|                             | 3            | Smooth             | 150                    | S15a6,S15a9,S15a12   |
|                             | 3            | Rough              | 150                    | S15b6,S15b9,S15b12   |
|                             | 3            | Smooth             | 200                    | S20a6,S20a9,S20a12   |
|                             | 3            | Rough              | 200                    | S20b6,S20b9,S20b12   |

Total of slabs concrete specimens =18

**Note:** "S10" represents slab series of 10 cm thickness, "S15" represents slab series of 15 cm thickness, and "S20" represents slab series of 20 cm thickness. "a" is representing the smooth interface, and "b" is representing the rough one. The addition 6, 9, & 12 represents the three separate slabs according to the movement rate 6, 9 and 12 cm/hr. respectively.

A hydraulic jack supported on the testing box's support wall has been utilized for the push-off test. The horizontally applied force has been evaluated using a load cell of (50 KN) capacity as shown in plate 1. The slabs roughly attached to the subbase were pushed by a hydraulic jack of (200 KN).
capacity. The slab's horizontal displacement was monitored with two linear variable differential transformers (LVDT) (an electrical converter used to calculate linear displacement). The experimental test slab setups with the hydraulic jack, (LVDT), load cell, data logger, and computer were similar approaches used previously by [2].

For slabs with a smooth interface, a (125µm) thick polyethylene sheet has been laid flat with no creases over SGM before pouring the concrete slab. The push-off test has been carried out by applying the horizontal force on slabs. For every one of the series, the push-off test was conducted in three different movement rates (6, 9, and 12cm/h); the mean value of displacements was recorded by two (LVDT), which represent slab displacement.

Plate 1. Slabs test with a hydraulic jack, pump, load cell, (LVDT), data logger, and computer, as well as other parts

5. Results and Discussions
5.1. Friction Resistance Force versus Displacement Curves
For this push-off test series, several cycles were accomplished. Only the first value was taken as it represents the maximum friction resistance force (FRF) and has the most decisive influence on the displacement. This fact is supported by [2]. After performing all the checks and measurements, the slabs were lifted from the pit to inspect their bottom surfaces. It was found that the surfaces were very smooth when a polythene layer was used. This layer stayed fixed to the slab's bottom and created a flat plane for the slab to slide across the base. Even after removing the slabs, the subbase did not show any noticeable distress signs.

A thin coating of the base material was attached to the slab's bottom surface in the rough condition, which resists more than smooth condition. These statements help to justify the results in figure 4 and figure 5, which show the FRF with displacement relationships for two slabs in the same thicknesses (20 cm), movement rate (6 cm/hr.), and various interfaces conditions (smooth and rough).
The observations also agree with the results reported by [7]. From the maximum FRF against displacement relationships, the push-off tests' results are shown in tables 3, 4, and 5. The results show the displacement and its corresponding maximum FRF for two types of interface conditions (i.e., smooth and rough), three slab thicknesses, and three rates of movements. The initial $\mu$ at slab interface and subbase in every one of the cycles has been computed from (equation 1): $\mu = F / N$  
\[ \mu = \text{Initial coefficient of friction.} \]  
\[ N = \text{Weight of the slab, (KN).} \]  
\[ F = \text{Friction resistance force required for pushing the slab (KN).} \]  

### Table 3. Results of Push-off Test of Friction Characteristics (10 cm) Slabs Thickness

| Rate of movement | Slabs codes | Interface condition | Initial displacement (mm) | Max. FRF (KN) Initial cycle | Max. $\mu^*$ Initial cycle |
|------------------|-------------|---------------------|---------------------------|----------------------------|---------------------------|
| 6 cm/hr.         | S10a6       | Smooth              | 1.121                     | 0.94                       | 0.8                       |
|                  | S10b6       | Rough               | 2.002                     | 2.77                       | 2.35                      |
| 9 cm/hr.         | S10a9       | Smooth              | 1.502                     | 1.07                       | 0.91                      |
|                  | S10b9       | Rough               | 1.684                     | 3.15                       | 2.68                      |
| 12 cm/hr.        | S10a12      | Smooth              | 2.145                     | 1.27                       | 1.08                      |
|                  | S10b12      | Rough               | 2.564                     | 3.68                       | 3.13                      |

*Calculated from Eq. (1)*

### Table 4. Results of Push-off Test of Friction Characteristics (15 cm) Slabs Thickness

| Rate of movement | Slabs codes | Interface condition | Initial displacement (mm) | Max. FRF (KN) Initial Cycle | Max. $\mu^*$ Initial cycle |
|------------------|-------------|---------------------|---------------------------|-----------------------------|---------------------------|
| 6 cm/hr.         | S15a6       | Smooth              | 1.941                     | 1.1                         | 0.62                      |
|                  | S15b6       | Rough               | 1.88                      | 2.75                        | 1.55                      |
| 9 cm/hr.         | S15a9       | Smooth              | 2.214                     | 1.31                        | 0.74                      |
|                  | S15b9       | Rough               | 2.193                     | 2.86                        | 1.61                      |
| 12 cm/hr.        | S15a12      | Smooth              | 2.059                     | 1.42                        | 0.8                       |
|                  | S15b12      | Rough               | 1.907                     | 3.62                        | 2.05                      |

*Calculated from Eq. (1)
Table 5. Results of Push-off Test of Friction Characteristics (20 cm) Slabs Thickness

| Rate of Movement | Slabs codes | Interface condition | Initial displacement (mm) | Max. FRF (KN) | Max. µ* |
|------------------|-------------|---------------------|---------------------------|---------------|--------|
| 6 cm/hr.         | S20a6       | Smooth              | 1.885                     | 1.81          | 0.76   |
|                  | S20b6       | Rough               | 1.695                     | 7.26          | 3.08   |
| 9 cm/hr.         | S20a9       | Smooth              | 1.569                     | 1.92          | 0.81   |
|                  | S20b9       | Rough               | 1.448                     | 7.48          | 3.17   |
| 12 cm/hr.        | S20a12      | Smooth              | 1.776                     | 2.01          | 0.85   |
|                  | S20b12      | Rough               | 3.17                      | 7.63          | 3.24   |

*Calculated from Eq. (1)

5.2. Screening and Variables Analysis of Subbase Friction

The data analysis was performed by screening analysis to examine the impact of numerous parameters on the initial FRF, displacement and coefficient of friction for choosing the significant contributing variables, as proposed by [1]. Design of experiment (DoE) software is utilized in this work, with outcomes utilizing the Pareto chart. The charts show the significant parameters impacting the maximum coefficient of friction (MCF) and displacement. Regarding the coefficient of friction displayed in figure 6, the interface condition has the most significant impact, followed by the movement rate then thickness. For displacement in figure 7, the movement rate comes first, followed by interface condition then thickness, as illustrated below.

![Figure 6] Pareto Chart of the Standardized Effects
(response is Coeff. of friction (µ); α = 0.05)

![Figure 7] Pareto Chart of the Standardized Effects
(response is Dis. (mm); α = 0.05)

5.3. Effect of Interface, Thickness, and Movement Rate on the Initial coefficient of friction

Analysis of the data carried on by Minitab contour plot which is helpful to demonstrates relationships between different parameters, it was found that interface condition is the most affecting factor on the maximum µ followed by the movement rate and slab thickness. The experimental results indicated that the maximum µ increases at changing the interface condition from smooth to rough. The slab thickness showed less influence in both conditions, in agreement with the findings of [10], which found that doubling the thickness by 100% (from 4 to 8 in) increases the maximum frictional restraint by only 13%.

Generally, the change interface condition from the smooth to the rough leads to raising maximum µ regardless of changing slab thickness or movement rate, as shown in figures 8 and 9. For example, at
(10 cm) slab thickness and changing the interface condition from smooth to rough leads to an increase in the initial coefficient of friction of (6, 9, and 12 cm/hr.) by (193.75, 194.5, and 189.8 %), respectively. Regarding the slab thickness of 15 cm reduced in the initial as shown in figure 8. For instance, increase slab thickness from (10 cm) to (15 cm) at smooth interface condition of (6, 9, and 12 cm/hr.) leads to a reduction MCF by (22.5, 18.7, and 25.9 %) respectively, while at rough condition by (34, 39.9 and 34.5 %) respectively. The findings match previous studies by [7] and [2]. Also, the rate of movement is a lower sensitive factor on MCF; however, raise the rate of movement leads to an increase in MCF as shown in figure 9. For example, when the rate of movement changes from (6 cm/hr.) to (12 cm/hr.), at smooth interface condition for (10, 15, and 20 cm) slab thickness, MCF by (35, 29 and 11.8 %), respectively, while at rough condition by (33.2, 32.2 and 5.19 %), respectively.

Figure 8. Effects of slab thickness and interface on μ
Figure 9. Effects of the interface and rate on μ

6. Conclusions
These can be described as follows:

1. The initial FRF will not change significantly regardless of the raise slab thickness or movement rate, where both of these factors below the influence line of screening analysis.
2. The maximum value of friction resistance force represents by the initial FRF detected in the primary force application.
3. Changing interface conditions from smooth to rough leads to increased friction resistance forces due to surface texture and high gradation of type A subbase and reduced initial displacement because removing the separator layer will create more interlock between surfaces.
4. When designing rigid pavement, coefficient of friction could help by measuring the friction factor in the maximum tensile stress equation \( \sigma_c = f_a * L * y_c * 0.5 \).
5. The subbase's elastic characteristics in the shearing direction affect the movement-friction response of the subbase because subbase has many types, each one has different characteristics.
6. Relating the interface condition, when smooth interface the movement rate has almost no effect on the coefficient of friction, but it grows with the rising of movement rate in rough condition.
7. Good agreement was found when comparing results from this work against previous studies data.
8. In smooth condition, the polythene film will be attached to the slab's bottom, thus creating a smooth surface for the slab to slip above the subbase, leading to less friction.
9. If a failure occurs at the slab-subbase interface, then the magnitude of frictional resistance is immediately dependent on slab weight.
10. When the slab thickness is (10 or 20 cm), the coefficient of friction changes from minimum to maximum of its value once the interface change from smooth to rough condition, but stays convergent in slab thickness of 15 cm, even after changing interface condition.
11. A polythene sheet tends to be a very efficient friction reducer whenever a polythene sheet is used between a subbase and a slab; without it, the bond between SMG and slab will be solid and resist more force.

7. References

[1] Abdulridha, M. A., Salman, M. M., & Banyhussan, Q. S. (2020). Prediction the Strength of Fibered Reinforced Concrete Pavement Using Response Surface Methodology: Parametric Study. Paper presented at the IOP Conference Series: Materials Science and Engineering. https://doi.org/10.1088/1757-899X/881/1/012180

[2] Al-Fahdawi, J. Z. (2020). USING ECO-FRIENDLY CONCRETE MIXTURE FOR MINIMUM CRACKS RISK IN CONCRETE PAVEMENT AT EARLY-AGE. (89). Mustansiriyah University, Retrieved from http://t.ly/yK1Z (Special_Issue_2020). http://t.ly/yK1Z

[3] Al-Fahdawi, J. Z., & Banyhussan, Q. S. (2020). Optimization of Eco-friendly Pavement Concrete Mixture Using Response Surface Methodology. Paper presented at the IOP Conference Series: Materials Science and Engineering. https://t.ly/OXNk

[4] Diaz, A., Burns, N., & McCullough, B. (1986). BEHAVIOR OF LONG PRESTRESSED PAVEMENT SLABS AND DESIGN METHODOLOGY. Research Report 401-3, Center for Transportation Research, The University of Texas at Austin, November 1986. Retrieved from http://t.ly/n9TM

[5] Jeong, J.-H., Park, J.-Y., Lim, J.-S., & Kim, S.-H. (2014). Testing and modelling of friction characteristics between concrete slab and subbase layers. Road Materials and Pavement Design, 15(1), 114-130. https://doi.org/10.1080/14680629.2013.863161

[6] Lee, S. W. (2000). Characteristics of friction between concrete slab and base. KSCE Journal of Civil Engineering, 4(4), 265-275. http://t.ly/NM9Y

[7] Maitra, S., Reddy, K., & Ramachandra, L. (2009). Experimental evaluation of interface friction and study of its influence on concrete pavement response. Journal of transportation engineering, 135(8), 563-571. http://t.ly/AE1w

[8] Oladiran, O. G. (2014). Assessment of restrained shrinkage cracking of concrete through elliptical rings. Brunel University School of Engineering and Design PhD Theses, Retrieved from http://bura.brunel.ac.uk/handle/2438/8224 http://bura.brunel.ac.uk/handle/2438/8224

[9] SCRB. (2003). General Specifications for Roads and Bridges, Ministry of Housing and construction, Iraq. https://t.ly/G27Q

[10] Wesevich, J., McCullough, B., & Burns, N. (1987). STABILIZED SUBBASE FRICITION STUDY FOR CONCRETE PAVEMENTS. INTERIM REPORT. Retrieved from https://t.ly/CwGE

Acknowledgment

The researchers are thankful to the Mustansiriyah University, Faculty of Engineering, Road and Transport Department, regarding their assistance and guidance to fulfill this research's humble study. This thesis did not obtain any particular fund from supporting organisations, private, or not-for-profit sectors in the contained of this research.