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EXPERIMENTAL INVESTIGATION OF THE DIRECTIONAL CONTROL CAPABILITY OF 18 × 5.5, TYPE VII, AIRCRAFT TIRES ON WET SURFACES

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Pages 17 and 18: In the key for the three-groove, six-groove, and dimple tread tire data, the symbols were inadvertently omitted. They should be as follows:

○ Three-groove tread

□ Six-groove tread

◇ Dimple tread

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16. Abstract

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SUMMARY

An experimental investigation was made to evaluate the free-rolling cornering capability of a high-speed aircraft nose-wheel tire. Data were obtained for several 18 × 5.5, type VII tires with three tread designs (three-grooved, six-grooved, and dimple) at wheel yaw angles up to 30° and ground speeds up to 110 knots, on various wet and flooded test surfaces. The results show a characteristic variation of cornering capability with wheel yaw angle and suggest a maximum cornering capability at an angle of approximately 10°. The surface texture, wetness condition, and ground speed are shown to have a pronounced effect on the cornering capability of the test tires. The results also show that the tires with three- and six-grooved-tread designs developed cornering capability that was comparable to and significantly greater than that of the dimple-tread tires.

INTRODUCTION

A survey of incidents experienced by aircraft during landing or aborted take-off reveals that those resulting from a loss of directional control far exceed those resulting from a lack of braking capability. Stated concisely, more aircraft leave the side of the runway than the end of the runway. For directional control on the ground, an aircraft must produce a normal force or yawing moment which can be supplied by one or more of the following: rudder action, differential thrust, differential braking or nose-wheel steering. For operations on a dry runway, the steering or cornering capability of the nose-gear tires is the most convenient single force available to the pilot to control the direction of the airplane. However, tests have shown (refs. 1 to 4, for example) that the cornering capability of a tire deteriorates if the runway surface becomes wet. This degradation in steering capability is of special significance to fighter-type aircraft which rely principally upon nose-wheel steering for directional control. The tests of references 1 to 4 were performed at various wetness conditions but only at one or two yaw angles and, as such, do not completely describe tire cornering behavior. Particularly lacking is information which describes the variation of the available cornering force over a range of yaw angles, including the angle at which maximum cornering is developed.

The purpose of this paper is to present the results of an experimental study to evaluate the free-rolling cornering capability of a high-speed aircraft nose-wheel tire over a wide range of yaw angles on a variety of wet and flooded runway surfaces. Also presented are the results from a comparative study to evaluate the effects of three tire-tread designs on the cornering force. Tests were performed on 18 × 5.5, type VII tires at ground speeds up to approximately 100 knots and at wheel yaw angles up to 30°, and at zero caster and camber. The results of these tests are presented in terms of the cornering-force friction coefficient, which is the force measured perpendicular to the direction of motion divided by the vertical load on the tire.

SYMBOLS

Principal measurements and calculations were made in U.S. Customary Units and converted to SI Units.

V ground speed, knots

w runway groove width, cm (inch)

μ_y cornering-force friction coefficient, $\frac{\text{Cornering force}}{\text{Vertical force}}$

ψ wheel yaw angle, degrees

TEST APPARATUS

Tire

The test tires used in this investigation were size 18 × 5.5, 14-ply rating, type VII, aircraft tires which are used as nose-wheel tires on several current high-speed aircraft. These tires (see fig. 1) had three tread patterns: a six-grooved tread, a three-grooved tread, and a dimple tread. Several tires with each tread pattern were used during these tests. Each tire was tested with an inflation pressure of 1 MN/m^2 (145 lbf/in^2). The maximum tread wear was limited to approximately 50 percent of the original tread which, as indicated in reference 5, was considered to have a negligible effect on the test results. The worn appearance of the tires in figure 1 is due to the exposed fabric reinforcement of the tread.

Test Surfaces

Cornering data were obtained from nine test surfaces, each in a damp or flooded state. These surfaces were installed end to end along the test section of the Langley landing loads track and elevated 10.2 cm (4 in.) above the concrete base. Entrance and terminal ramps were installed to provide the tires with smooth access to and from the test surfaces. The test surfaces are pictured in figure 2 and identified and briefly described in the schematic of figure 3. Test surface 1 was a smooth finish concrete which contained very small aggregates and was painted to yield a very smooth finish. Surfaces 2 and 3 consisted of a mixture of a masonry sand and a commercial grade of an epoxy compound (used to repair or patch concrete) spread to a depth of 0.32 cm (1/8 in.) over a concrete base. Coarse grain masonry sand was used in the mixture of surface 2 whereas surface 3 was prepared with fine grain sand. Surfaces 4, 5, and 6 were reinforced concrete slabs with transverse-flailed grooves 0.32 cm (1/8 in.), 0.64 cm (1/4 in.), and 0.95 cm (3/8 in.) in width, respectively. The groove pattern for all three surfaces consisted of a pitch of 3.85 cm $\left(1\frac{1}{2}\text{ in.}\right)$ and a depth of 0.32 cm (1/8 in.). Surfaces 7, 8, and 9 consisted of the MX-19 runway mat with coarse, medium, and regular size grain aggregate, respectively. Surface 9, the regular-size grain aggregate, is standard, whereas the other two mats were specifically resurfaced for these tests. Figure 4 is a photograph of a slab of grooved concrete (fig. 4(a)) and a section of the MX-19 runway mat equipped with a regular-size grain aggregate (fig. 4(b)). Some idea of the texture of each test surface may be obtained from the photographs presented in figure 5.

Test Facility

The investigation reported herein was performed at the Langley landing loads track with the high-speed test carriage. A description of this facility is given in references 6 to 8. A photograph of the test carriage is given in figure 6. A closeup view of the test fixture with a six-groove tire installed is shown in figure 7. This fixture supported the test tire through a force balance which measured the vertical load applied to the tire and forces parallel and perpendicular to the wheel plane. The test fixture was designed to provide the tire with fixed yaw angles as high as 80°. A detailed description of the fixture is given in reference 3.

TEST PROCEDURE

The testing technique involved propelling the carriage to the desired velocity at which the tires rolled over the nine test surfaces, and recording the forces generated in the different tire-surface interfaces. Test velocities ranged from 8 to 110 knots and remained essentially constant throughout the test section.

The test wheel was set at a predetermined yaw angle which ranged from 0^{o} to 30^{o}, and the pneumatic loading system (ref. 3) was adjusted so that a nominal vertical load of 14.7 kN (3300 lbf) was applied to the wheel when the tire was in contact with the test surfaces. Tests were made when the surfaces were in the damp and flooded states. Damp surfaces were obtained by first flooding the surface and then sweeping the excess water from the surfaces with a stiff brush. In the flooded state, dams (noted in fig. 2) were installed on either side of the test surfaces and the surfaces were kept flooded with water to a depth of approximately 0.8 cm (1/3 in.). This depth was selected so that the water depth was greater than the groove depth of the tires. Immediately prior to launch, a recorder on board the carriage was started to provide a history of forces parallel and perpendicular to the test-wheel plane throughout the test run on the different surfaces.

Tests were made with the three-grooved tread tire freely rolling on the test surfaces at various yaw angles and two ground speeds. Tests were made with all tires at one selected representative yaw angle for a broad range of ground speeds.

RESULTS AND DISCUSSION

The cornering force as defined herein is the force developed in the tire-surface interface perpendicular to the direction of vehicle motion. This force was computed from the data recorded as the tire traversed each of the nine test surfaces and was converted to coefficient form by dividing by the vertical force acting on the tire. Thus, all data from the cornering tests are presented in terms of the cornering-force friction coefficient μ_y. In the sections which follow, data are presented to show: the effects of yaw (cornering) angle on the cornering capability of the test tire with a three-groove-tread pattern, a widely used tread design for this tire; and the effect of tread design on the tire cornering characteristics, accomplished at a fixed yaw angle.

Effect of Yaw Angle

The variation in the cornering-force coefficient with wheel yaw angle on the different test surfaces under damp and flooded conditions is presented in figures 8 and 9 for tires having a three-grooved-tread pattern. Data are presented at ground speeds of 38 and 75 knots for the damp surfaces (fig. 8) and at 8, 25, and 69 knots for the flooded surfaces (fig. 9). The figures show that for all ground speeds the cornering coefficient increased to a maximum as the yaw angle was increased and thereafter, where data are available, decreased gradually with further increases in yaw angle. This variation with yaw angle was characteristic for all test surfaces under both wetness conditions. The faired data from the damp test surfaces suggest that the maximum cornering capability for the three-grooved tires is developed at a yaw angle of approximately 10^{o}, regardless of the ground speed. This yaw angle also appears to define the maximum cornering coefficient on the flooded surfaces except for the low-speed test data where the maximum coefficient is seen to occur at somewhat higher yaw angles.

Figures 8 and 9 also show that the cornering-force coefficient decreases with increases in ground speed over the test range of yaw angles and corroborates the results from cornering data obtained at a limited number of yaw angles as presented, for example, in references 1 to 4. A comparison of the data of figure 8 with that for corresponding surfaces in figure 9 gives an indication of the loss in cornering capability attributed to hydroplaning. The critical hydroplaning speed for this tire, defined in reference 9, based on the tire inflation pressure of 1 MN/m^2 (145 lbf/in^2), is approximately 108 knots. On the flooded grooved surfaces a lower cornering-force coefficient was obtained than on the damp grooved surfaces, which is an apparent contradiction of the concept that grooved surfaces postpone the effects of hydroplaning. However, these data confirm the results of reference 10 for grooves of comparably shallow depth, 0.34 cm (1/8 in.) deep, and a relatively heavy flooded surface condition, 0.51 cm to 0.76 cm (0.2 in. to 0.3 in.).

An examination of the relative cornering capability of the tire on the different test surfaces suggests several general comments. The epoxy-finished concrete having a coarse-grain sand aggregate provided the largest cornering-force coefficient of all surfaces tested in both the damp and flooded states. The cornering-force coefficients associated with the medium-grain runway mat were the lowest for all surfaces tested. Finally, the figure shows that there is no pronounced effect on the cornering-force coefficient due to changes in the width of the flailed grooves ranging between 0.32 cm (1/8 in.) and 0.95 cm (3/8 in.).

Effect of Tire-Tread Pattern

Cornering tests were also conducted on 18×5.5 tires equipped with a six-grooved and a dimple tread in addition to the previously discussed three-grooved tread to evaluate the effects of tread pattern on the steering capability of this tire size. These tests were performed at a fixed yaw angle of 10° which gave the higher cornering-force coefficients noted in figures 8 and 9. The cornering-force coefficients for the different tread patterns are presented as a function of ground speed in figures 10 and 11. Again, data were obtained during operations on the nine test surfaces under both damp and flooded conditions. On all test surfaces under both wetness conditions, the nose-wheel steering capability of the three- and six-grooved-tread tires is comparable, and is significantly greater than that of dimple-tread tires throughout the test speed range. The low cornering capability exhibited by the dimple-tread pattern corresponds to the findings of reference 11 where a dimple-tread tire (32×8.8, type VII) was shown to develop braking coefficients of friction which ranged from one-half to one-third of those developed by a rib-tread tire on damp and flooded concrete. This difference in traction indicates that dimple-tread tires are more susceptible to hydroplaning effects than are rib-tread tires for operations on damp and flooded surfaces.

Figures 10 and 11 also illustrate the general decrease in cornering-force coefficients with increasing ground speed for all tread patterns on all test surfaces. The figures show that the rate of decrease for all tread patterns is more pronounced on the flooded surfaces than on the damp surfaces and that, in general, the trend of the data for the flooded condition is to approach negligible cornering effectiveness at the hydroplaning speed of 108 knots.

CONCLUDING REMARKS

An experimental investigation was made to evaluate the free-rolling cornering capability of a high-speed aircraft nose-wheel tire over a wide range of yaw angles on a variety of wet and flooded test surfaces. Cornering data in the form of cornering-force friction coefficients were obtained at ground speeds up to 100 knots on three-grooved-, six-grooved-, and dimple-tread tire designs. The results of this investigation suggest the following conclusions:

1. For all ground speeds, the cornering-force coefficient increases to a maximum as the yaw angle is increased and, thereafter, decreases gradually with further increases in yaw angle. This variation, which was characteristic for all test surfaces and wetness conditions, generally indicated a maximum value at a yaw angle of approximately 10°.

2. The cornering force generally decreases with ground speed over the range of yaw angles.

3. The epoxy-finished concrete having a coarse-grain sand aggregate provided the largest cornering force, whereas the smallest cornering force was provided by the runway mat resurfaced with an aggregate of medium size. The shallow flailed grooved surfaces were not very effective in alleviating the reduction of cornering force under a relatively heavy flooded surface condition.

4. The cornering force obtained with the three- and six-grooved-tread tires was comparable and was significantly greater than that of the dimple-tread tires.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., February 12, 1971.

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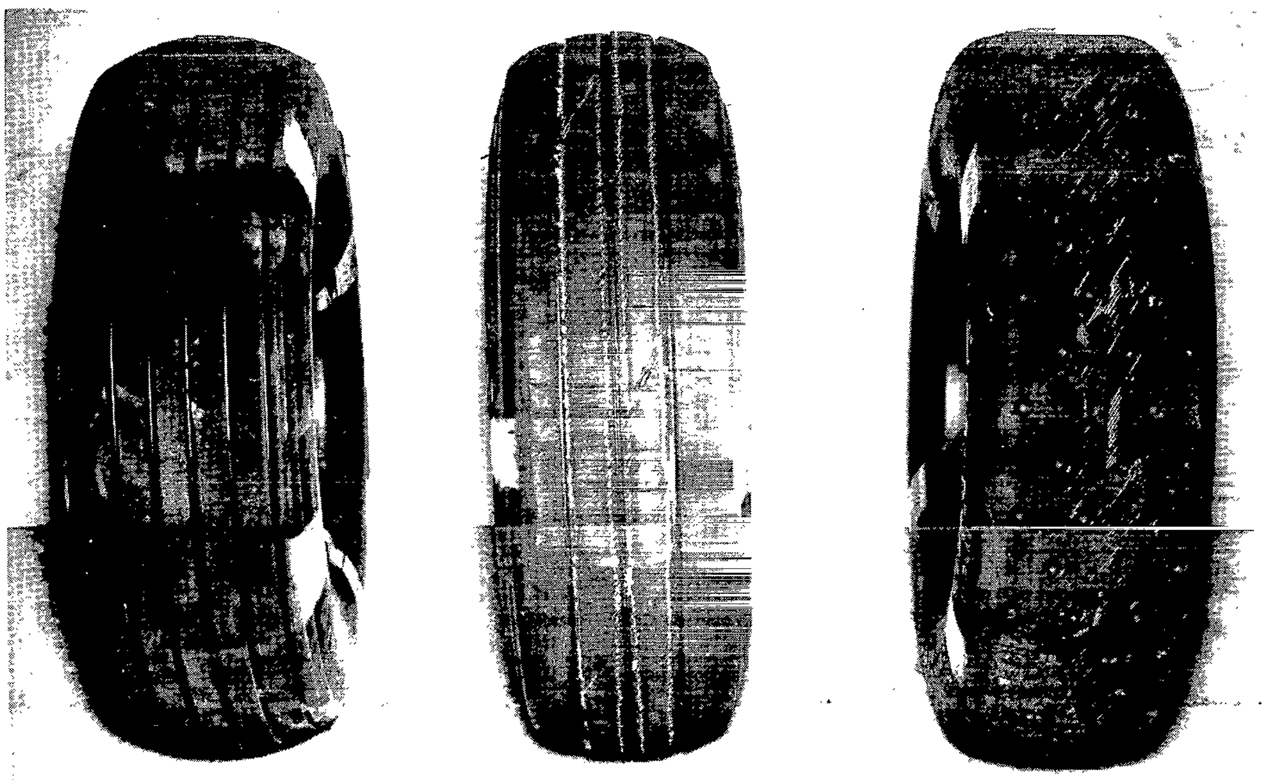

Six-groove tread Three-groove tread Dimple tread

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Figure 1.- 18 × 5.5, type VII, aircraft test tires.

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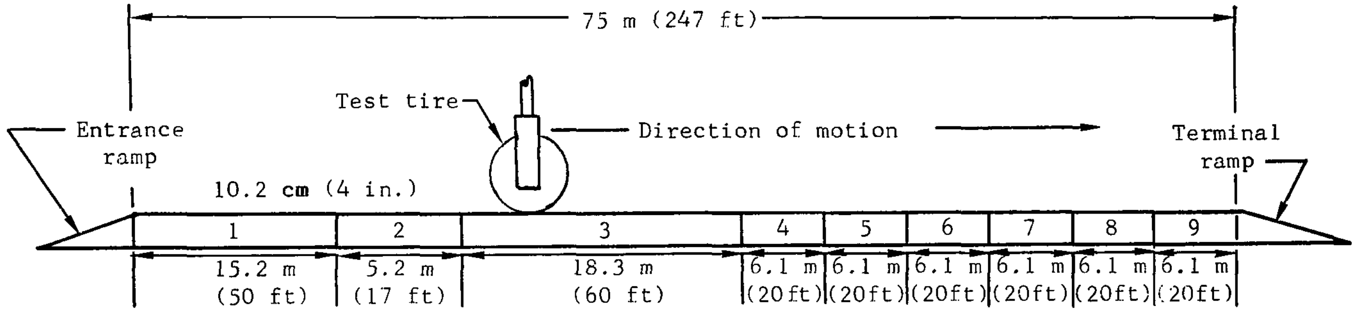
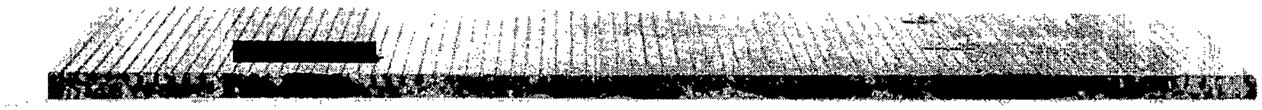
Figure 2.- Test surfaces at Langley landing-loads track.

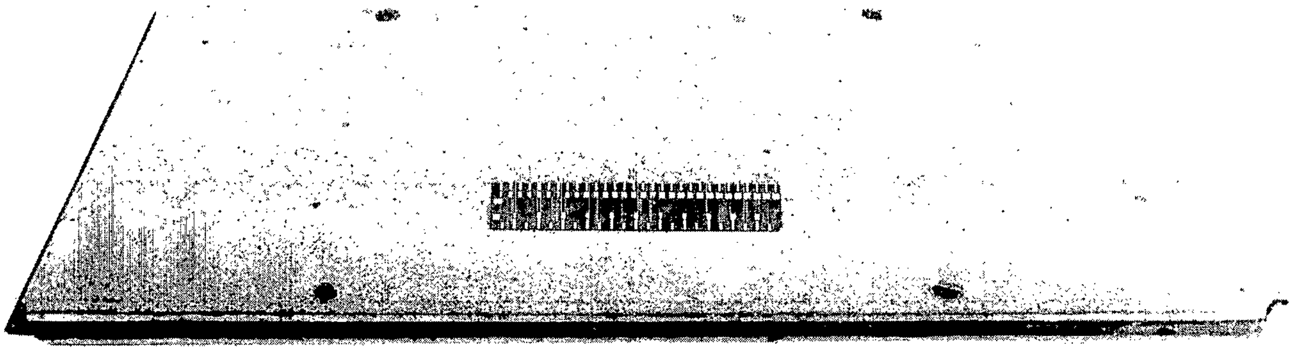


Test surface identification	Test surface description
1	Smooth-finish concrete
2	Epoxy-finish concrete (coarse-grain sand)
3	Epoxy-finish concrete (fine-grain sand)
4	Flail grooved concrete 3.81 cm X 0.32 cm X 0.32 cm ($1\frac{1}{2}$ in. X $\frac{1}{8}$ in. X $\frac{1}{8}$ in.)
5	Flail grooved concrete 3.81 cm X 0.64 cm X 0.32 cm ($1\frac{1}{2}$ in. X $\frac{1}{4}$ in. X $\frac{1}{8}$ in.)
6	Flail grooved concrete 3.81 cm X 0.95 cm X 0.32 cm ($1\frac{1}{2}$ in. X $\frac{3}{8}$ in. X $\frac{1}{8}$ in.)
7	Coarse-grain runway mat
8	Medium-grain runway mat
9	Regular-grain runway mat

Figure 3.- Description of test surfaces.



(a) Grooved concrete slab.



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(b) MX-19 runway mat.

Figure 4.- MX-19 runway mat and grooved concrete slab.

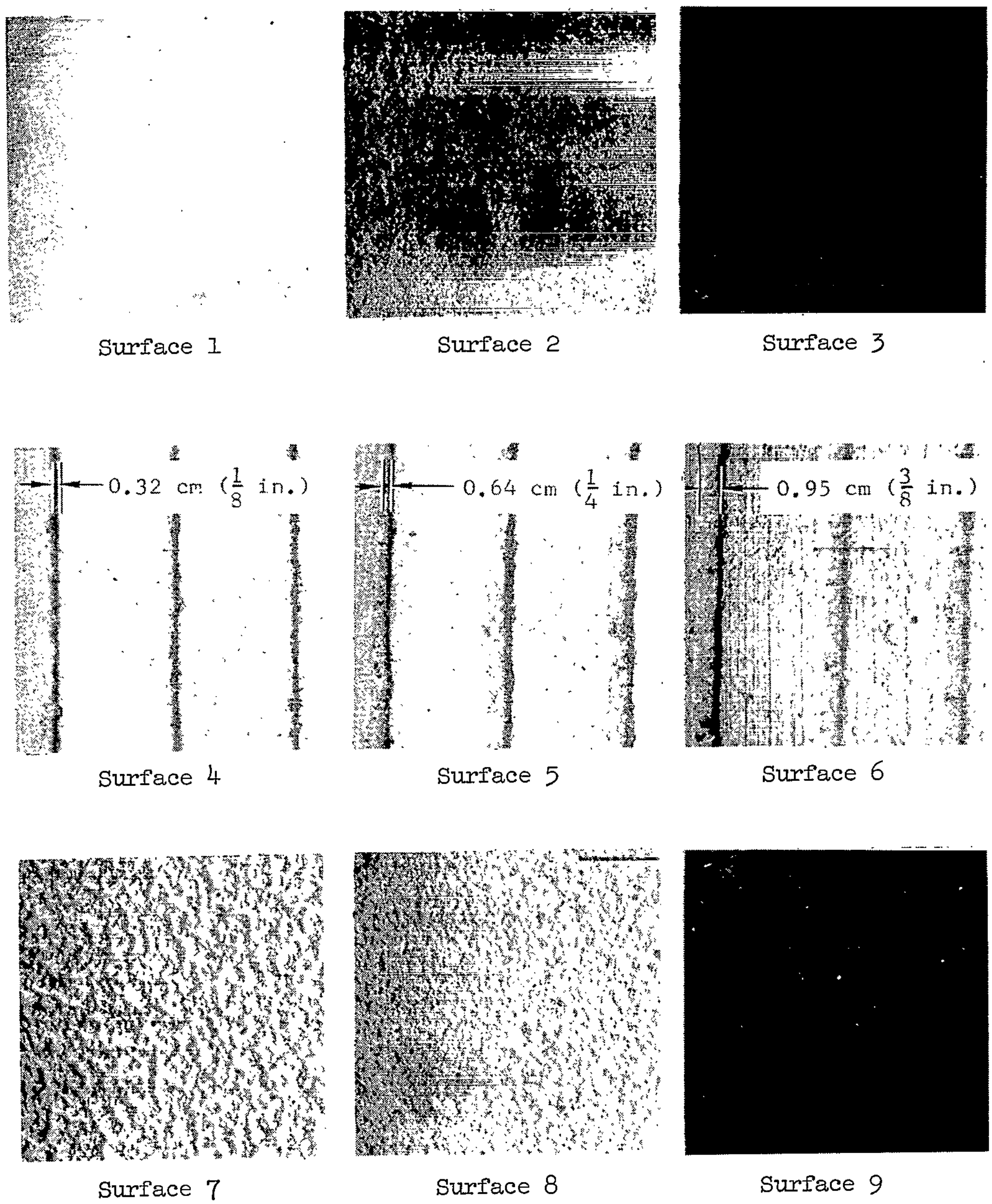

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Figure 5.- Test-surface textures.

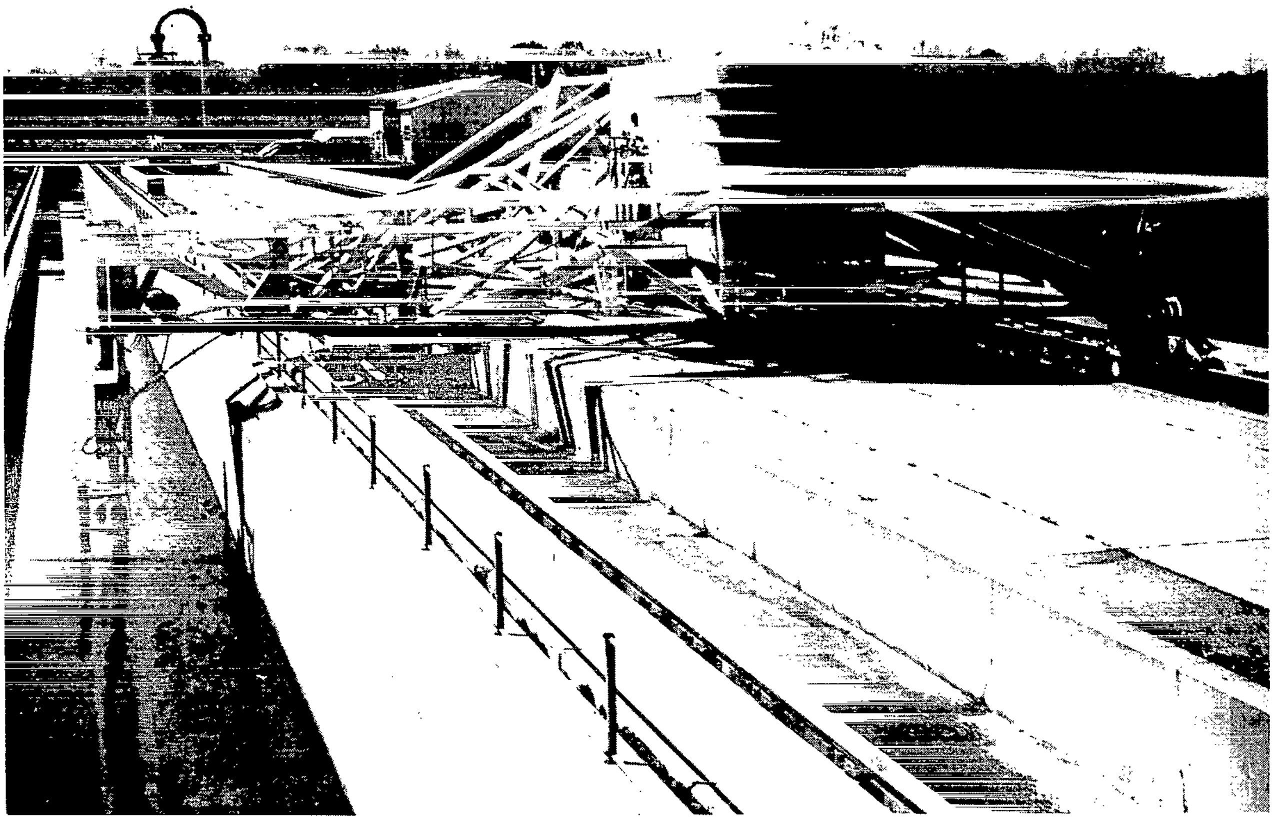

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Figure 6.- High-speed carriage.

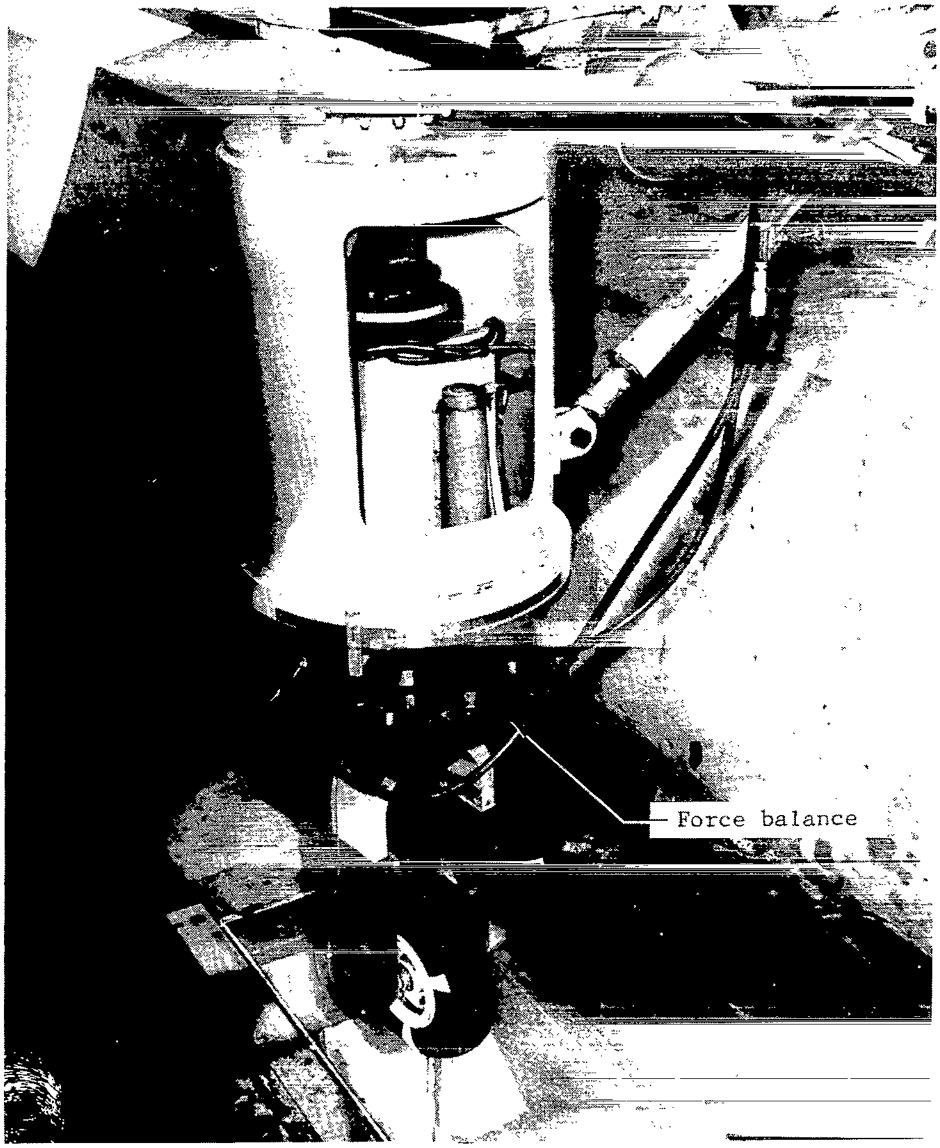

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Figure 7.- Closeup view of test fixture with tire installed.

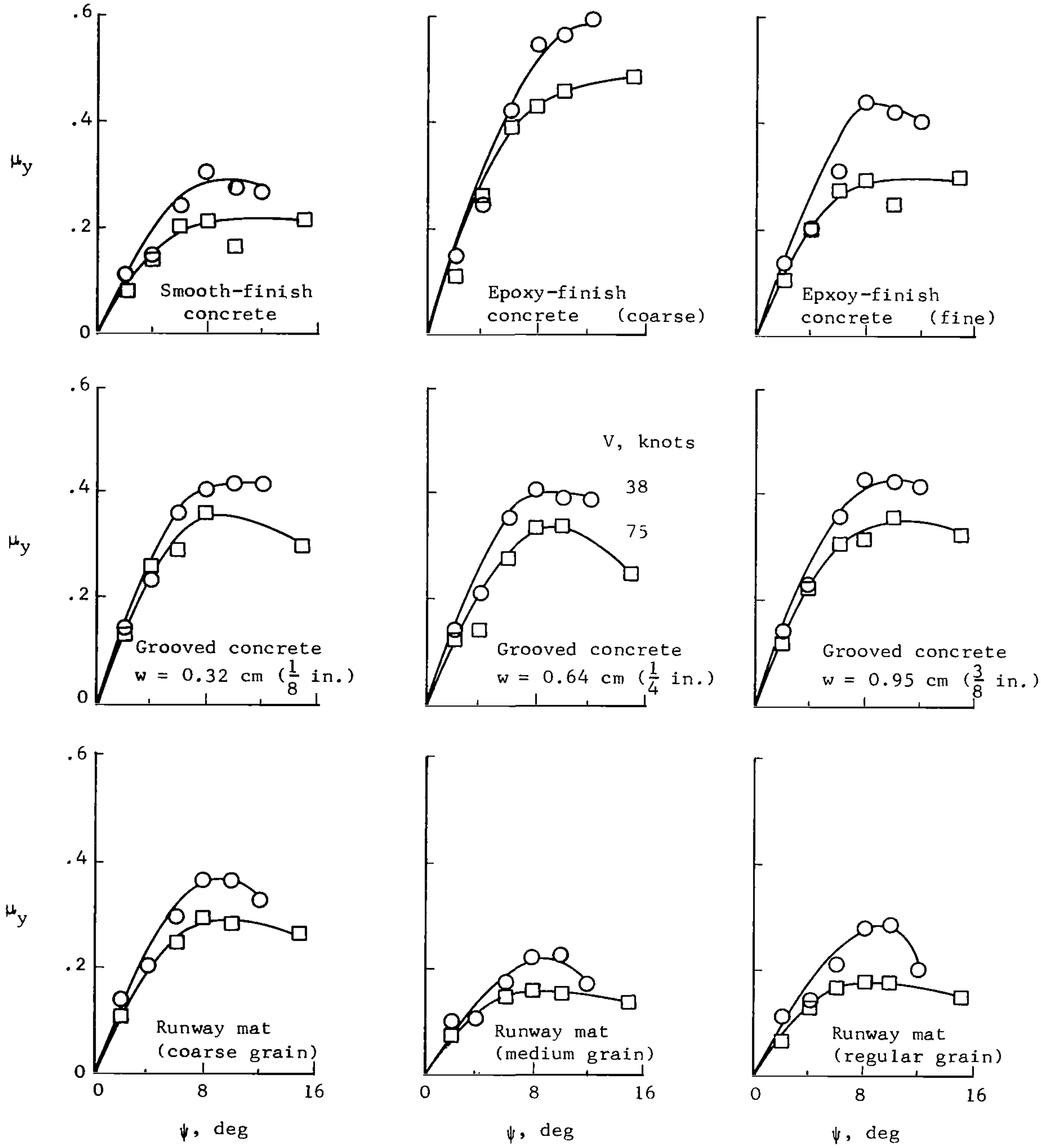

Figure 8.- Variation of cornering-force friction coefficient with wheel yaw angle for a three-groove-tread tire on the damp test surfaces.

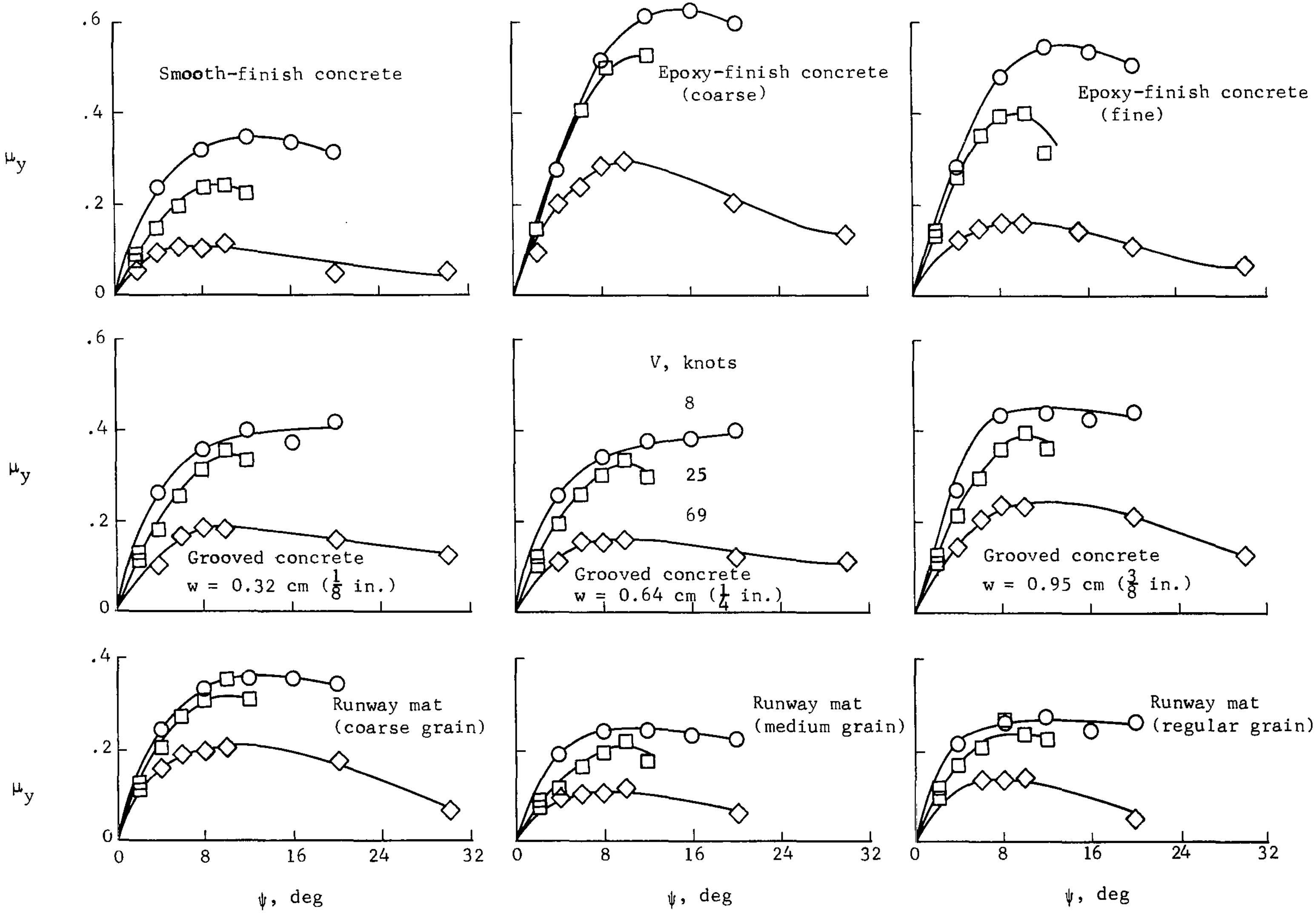

Figure 9.- Variation of cornering-force friction coefficient with wheel yaw angle for a three-groove-tread tire on the flooded test surfaces.

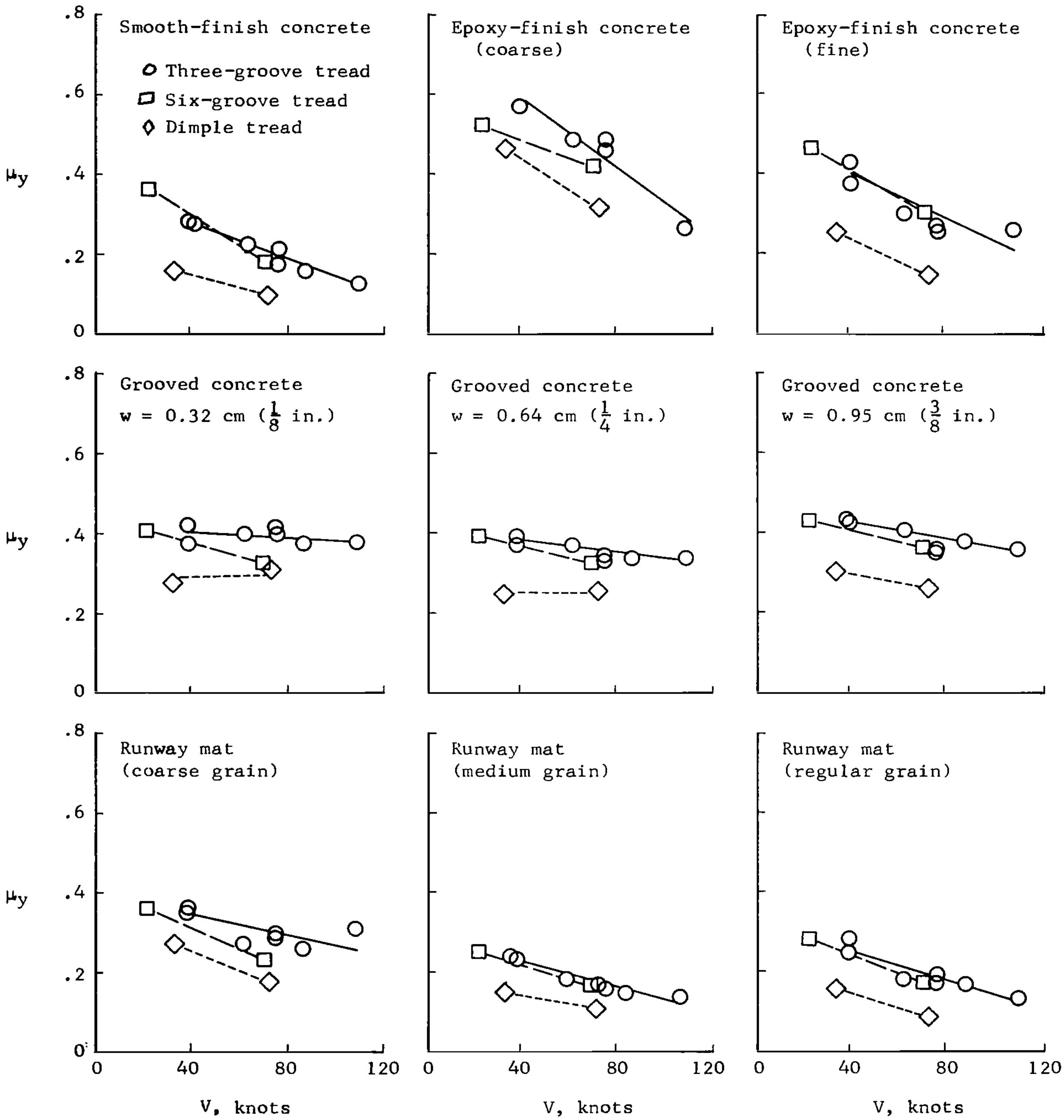

Figure 10.- Effect of tire-tread pattern on cornering-force friction coefficient for the test tires on the damp test surfaces. $\psi = 10^{\circ}$.

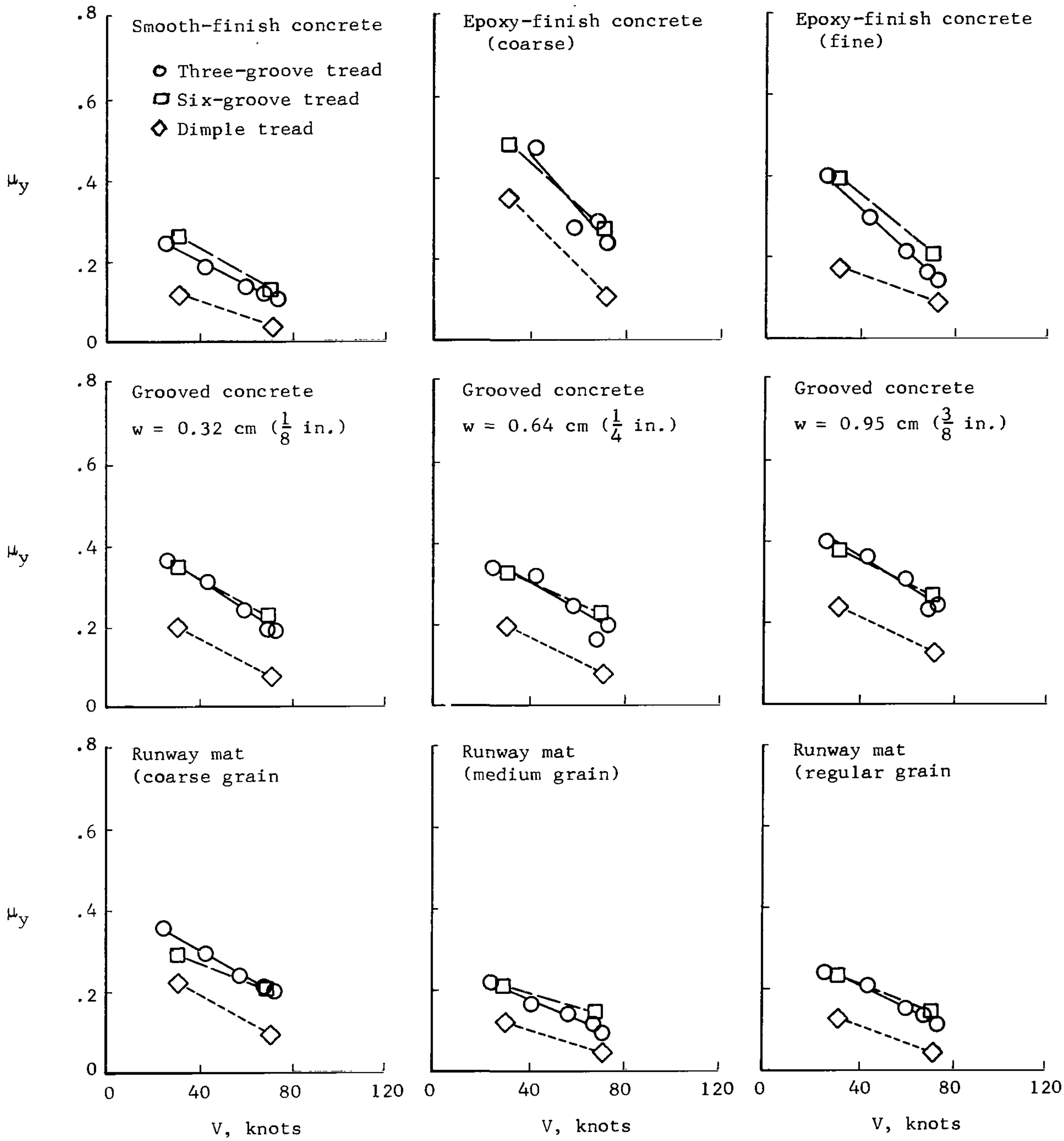

Figure 11.- Effect of tire-tread pattern on cornering-force friction coefficient for the test tires on the flooded test surfaces. $\psi = 10^{\circ}$.

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