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NEW HEMISPHERE AIRPORTS UNITE THE AMERICAS

BY NORRIS M. MUMPER*

SCORES of airports and landing fields have been constructed in the Americas in recent months, despite many wartime obstacles. There is little doubt, however, that the airport construction program that we see going on in the United States and the 20 other American republics will be continued, as a result of the demands of post-war expansion of commercial aviation.

It is a truism that expansion of aviation and airport facilities proceed together. This has been demonstrated in the rapid development of commercial aviation in the Western Hemisphere since the outbreak of war. With the expansion of commercial aviation in the post-war period, which some estimates place as high as at least three times the present service, many new airports will be needed.

The new airports are bound to play an important role in bringing about closer economic, political and spiritual relations among the Americas. Already airports have proven themselves to be stepping-stones to greater inter-American unity.

There is no way, of course, of knowing exactly how great the

*Director of Aviation, Office of Inter-American Affairs, Washington, D. C. Mr. Norris M. Mumper received his academic training at Dickinson College, and post graduate mechanical engineering course at Columbia University. He has travelled extensively in Europe, the Orient and in Latin America. In World War I, he was Captain Adjutant 309 Field Artillery, 78th Division, with one year's service in France.

His aviation experience began in 1938 with Vultee Aircraft, as Latin American Sales Manager. His government work started in 1941 with the American Republics Aviation Division of Defense Supplies Corporation. Later he joined the Office of Inter-American Affairs as Director of Aviation, in which position he is in constant touch with all phases of aviation throughout the other American Republics.

post-war development of airports is likely to be, but some idea can be gained by present and post-war trends that are already evident. For example, airport construction trends in the United States not only show the sizable increase in airport facilities that has taken place here since the outbreak of war but also give reason for believing that existing United States airport facilities may possibly be doubled in the post-war period.

In the United States, with the completion of more than 550 airport development projects undertaken by the Civil Aeronautics Administration at a cost of $400,000,000, there will be, at the close of 1944, more than 3,000 civil airports, of which 940 will be class III or better—that is, suitable for scheduled air carrier transport.

But because of the anticipated post-war expansion of aviation in the United States, the Civil Aeronautics Administration has recommended that the United States' goal of 4,000 airports, which was originally projected in 1939, now be raised to a post-war goal of 6,000 airports, within five to ten years after hostilities cease. This proposed post-war program will cost approximately $1,000,000,000.

Latin America has similarly undergone rapid airport expansion since the war began. In the 20 other American republics, at the close of 1944, there will probably be more than 2,400 civil airports, of which between 300 to 400 will be class III or better. Because expansion of airport facilities must go hand in hand with expansion of commercial aviation, the other Americas will obviously experience airport expansion of record-breaking proportions in the post-war world.

News reports of aviation and airport developments "south of the border" illustrate how present and future airport trends in the United States are duplicated in the other Americas. In Peru, for instance, President Manuel Prado, in order to prepare for the post-war aviation expansion anticipated in his country, recently decreed the formation of the Peruvian Airport and Commercial Aviation Corporation (CORPAC), a corporation owned entirely by the Peruvian Government, which will have an initial capital of $1,538,000 (10,000,000 soles). The charter gives this new agency wide powers to organize and manage airports.

Projected improvements for the airport at Lima will cost $183,000 (1,200,000 soles). In the neighboring Republic of Chile, President

Juan Antonio Rios is reported by the Chilean radio to have signed appropriations of $646,000 (20,000,000) pesos) to be used, in part, for the construction of a network of airfields throughout the nation. In Brazil, Air Minister Joaquim Pedro Salgado, Jr., is reported to have told the press that several large airfields, capable of accommodating large cargo planes, and also a pilot training school would be built in the State of Rio Grande do Sul.

In Nicaragua airline facilities were increased substantially during 1943 with the completion of the modern Las Mercedes Airport, the second airport near Managua, and the inauguration of two new lines—one, a common carrier, to New Orleans, Louisiana, from Balboa, via Guatemala City and Merida, and the other, a charter service, to Miami, Florida, from San Jose, Costa Rica, via Tegucigalpa and San Salvador. In recent years, especially during 1943, airports have been built in the remote jungles of eastern Nicaragua, making possible the shipment of machinery to the gold mines and the transportation of men, supplies and foodstuffs to the rubber-tapping areas. These airports made possible the necessary quick shipment of highly perishable Hevea rubber seedlings and budwood of high-yielding clones, cinchona seedlings, derris cuttings, and other strategic plant stock isolated areas. Without the aid of airways, establishment of these complementary agricultural crops in eastern Nicaragua would have been impossible, the Department of Commerce reports.

In Paraguay, Panair do Brasil's new airfield, near Asuncion, the capital, was opened in April. In Ecuador the airport-extension project at Guayaquil has been completed. According to the Ecuadoran Foreign Office bulletin, Ecuador plans to construct a network of airfields near its principal cities that will in the future facilitate national air transportation. Mexico, which has a splendid modern airport at Monterrey, will have two new ones soon—at Neuvo Laredo, across the border from Laredo, Texas, and at Mexico City. The airport at Mexico City, an expansion of the present Aeropuerto Central, will boast five main runways ranging in length from 5,740 feet to 8,200 feet, and several smaller runways, according to the Mexican press. The area of the field will be almost twice as large as that of New

York's famed LaGuardia Field. Its passenger terminal will be capable of accommodating 1,800 persons at one time.

Mexico also furnishes a striking example of how commercial air service has expanded in Latin America, as it also has in the United States, despite wartime shortages of planes, equipment, and manpower.

According to Air Transport Information Division of the U. S. Civil Aeronautics Board, the 13 domestic and international air lines operating as common carriers in Mexico as of March, 1944, had unduplicated route mileage more than 15 per cent greater than the unduplicated route mileage flown by 12 common carrier air transport companies in March, 1943. Unduplicated route mileage of common carrier air-transport companies amounted to 19,222 miles in March, 1944, as compared with 16,664 miles in March, 1943. Of the 13 common carrier air transport companies operating in March, 1944, two were U. S.-flag carriers—Pan American Airways, Inc., with 1,743 unduplicated route miles, and American Airlines, Inc., with 1,521 unduplicated route miles, in Mexican services.

The size of the international passenger air traffic to Mexico in 1943 can be seen from the report of the Mexican Tourist Association (Associacion Mexicana de Turismo) that of the record total of 207,000 foreign visitors to Mexico last year, 37,000 of the 160,000 visitors not in transit came by plane, as compared with 35,000 by rail and 88,000 by road. Unlike Mexico, tourist travel by United States citizens elsewhere in Latin America is banned, but essential air travel on governmental and business matters between the Americas last year did, however, bring a gain in passenger traffic over previous years.

Although exact figures of the international passenger air traffic in the other Americas are not yet available, Panagra (Pan American-Grace Airways), which is one of the largest international airlines operating in South America, reported an increase of more than 21 per cent in passenger traffic in 1943 as compared with 1942 passenger traffic. Panagra announced that it carried 69,000 passengers as compared with 56,770 in 1942, that it flew 4,700,000 plane miles during the year as compared with 4,030,000 the year previous. Panagra's reported increase of more than 21 per cent in passenger air traffic is, incidentally, double the increase reported by the United States domestic air lines for 1943.

As for air freight, the Interdepartmental Air Cargo Priorities Committee, War Production Board, states that in the year 1943 the total movement of imported materials by air was 42,010,298 pounds, amounting to $119,890,402 in dollar value, of which 5,429,522 pounds, having a dollar value of $25,617,865, were flown to the United States from the 20 other American republics, including the Canal Zone. Most of these air shipments from Latin America consisted of vital war materials such as Brazilian quartz, mica, tantalite, beryllium, and crude rubber.

The foregoing are only a few of the developments in commercial aviation and airports reported recently by the press and radio, yet they afford sufficient evidence to identify the trends. There are important differences, however, between the aviation and airport outlook in the United States and the situation in most of Latin America that must be pointed out.

As William A. M. Burden, Assistant Secretary of Commerce, has emphasized in his book, "The Struggle for Airways in Latin America", most of the other American republics have mountainous areas, jungles and arroyas which have long retarded adequate ground transportation by highways and railroads. As a result of this and other common features, there was a rapid and early growth of air transportation in almost all these countries.

"The important place which the airplane has already taken in transportation in Latin America," Mr. Burden explains, "is made clear by the fact that there are as many miles of airlines in the area as there are miles of railroad. In only seven of the 20 republics does railroad mileage exceed airline mileage. Two of the South American countries and every one of the Middle American countries, except Haiti and the Dominican Republic, have more airline mileage per thousand square miles than has the United States."

Mr. Burden then expresses the opinion that Latin America is extremely fortunate in being the first important continent where the air transport system is having a chance to develop unhampered by the existence of what he calls "giant obsolescent surface transport systems". Hence, he doubts if ground transport systems will be built on anything like the scale that they would have if Latin America had already placed huge investments in the older forms of transport.

This novel dependence on air transport rather than railroads or highways in the interior will probably make the future development of local air transportation in some respects more important to Latin America than the growth of the international system which connects it with other continents.

A possible indication of post-war developments elsewhere in Latin America is the unusual success that air cargo planes have already achieved in mountainous Central America. There, Transportes Aereos Centro-Americanos (TACA) and its affiliates are credited with having carried more air cargo than all the domestic United States airlines combined. In 1941, for example, TACA carried 30,161,000 pounds of express and freight compared with 11,160,000 unduplicated poundage carried by U. S. domestic air carriers. On the other hand, the average distance a shipment was carried in the United States exceeded 500 miles while on TACA the average distance was probably nearer 150 miles.

TACA's success lies principally in the hauling of bulk freight cheaply in regions where surface transportation is difficult. In fact, more than 60 per cent of its income in 1940 was derived from air freight, as compared with less than three per cent earned by U. S. domestic air carriers from the carriage of express during the same year.

TACA's revenue from mail was some five per cent of its total income that year and from passengers, 31 per cent. TACA's freight revenue for all types of merchandise has averaged three cents per pound. TACA does not report ton-mile figures, but representative air express and air freight tariffs on TACA's lines, reduced to a ton-mile basis, would be approximately as follows: Managua-Bluefields—171 airline miles—air express, 98.3 U. S. cents per ton-mile; air freight, 49.2 U. S. cents per ton-mile.

Should similar air cargo service be developed elsewhere in Latin America in the post-war period, it would seem apparent that considerable expansion of airports and landing fields would be necessary to handle internal trade and trade with neighboring republics.

One new use of air cargo planes in the post-war period has been suggested in studies of the possibilities of air cargo shipments of fresh fruits and vegetables. These studies are being carried on by several United States Government agencies and private research organizations, including Wayne University, Detroit, under the Edward S. Evans Grant for Air Cargo Research. Papayas and figs, for example, can be picked only when they are tree-ripe. This prevented their shipment by rail over any considerable distance. If it is found that cargo planes can transport these and other fresh vegetables at not unreasonable costs in the post-war period, here again there will be a new need for airports and landing fields in the fruit and vegetable areas of the Americas so that cargo planes can collect such shipments.

As for post-war markets in Latin America, many foreign traders believe prospects are bright for maintaining U. S. exports to and imports from the other Americas. They point out, for one thing, that Latin America is building up substantial reserves of purchasing power for post-war use as a result of a heavy surplus of exports. According to the National City Bank of New York, the other American republics, as a whole, have accumulated gold and foreign exchange, mostly U. S. dollars, amounting to approximately $3,000,000,000. The bulk of this backlog of buying power has accumulated during the war period when United States imports from Latin America have risen to the highest level since 1920 in dollar value.

In the post-war period, greatly expanded shipments of air mail, air express and air freight are anticipated by many shipping specialists. Similarly, tourist and travel agencies expect greater air travel by business men, salesmen, engineers, students and tourists.

The war has brought about the realization by the American people that the economies of the United States and most of the other American republics largely are complementary. We now know that inter-American cooperation, based on the concept of mutual aid for mutual benefit, has a solid economic base. The $1,300,000,000 worth of imports the United States received from Latin America last year emphasized that.

The war also has stimulated the interest of the American peoples in each other. The number of United States citizens studying Spanish today is unprecedented. Similarly, the study of English in Latin America has reached new heights. Travel authorities believe this war-stimulated interest will be reflected in tourist travel after the war ends.

However, it would be well, in considering the post-war aviation outlook, to dismiss fantastic notions as to the size either of post-war transport planes or of airports.

"Notwithstanding the comic strip and pictorial magazine super-liners," Charles I. Stanton, former Administrator of the Civil Aeronautics Administration, cautioned recently, "the 20-to-60 passenger airplanes are going to be the backbone of domestic air transport systems for some years to come because they furnish long distance travel with inter-city bus schedule frequencies."

President Harold J. Roig of Pan American-Grace Airways has said that Panagra anticipates providing round-the-clock service on its Latin-American air routes after the war with 56-passenger Douglas DC-6s, powered with four engines and with a normal cruising speed of 278 miles an hour.

According to the airport classification standards of the Civil Aeronautics Administration, there will be, at the close of 1944, between 300 to 400 class III or better airports in the other American republics capable of handling the twin-engined, 21-passenger plane which is in general use on the Latin-American main air routes. Some of these airports—the exact number must be withheld for reasons of military security—already are in the class IV and class V category, equipped to accommodate the largest planes now in use and those planned for the immediate future. Construction is now under way or planned to create more class IV and class V airports.

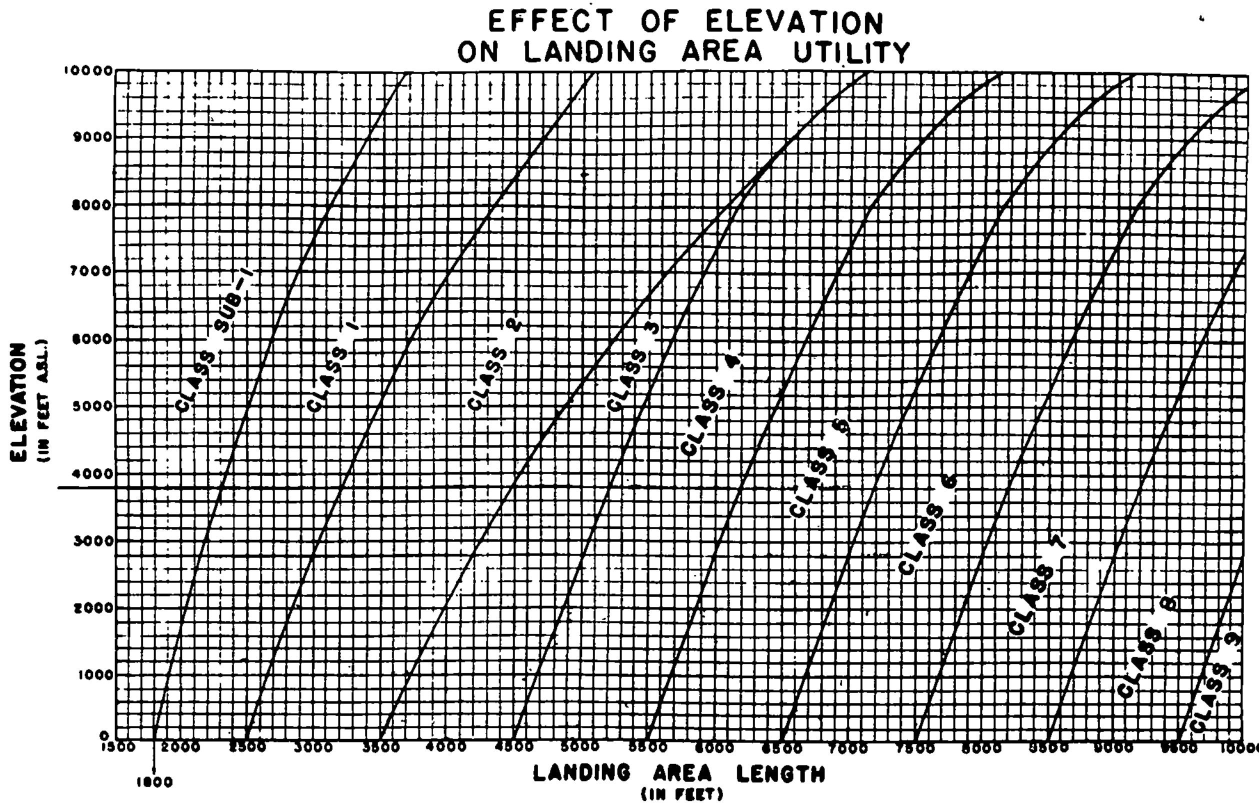
Under the Civil Aeronautics Administration's airport standards, a class three airport has landing strips 3,700 to 4,700 feet in length at sea level, and is suited for the safe handling of present-day transport planes. Planes in this classification are represented approximately by those between 10,000 to 50,000 pounds gross weight, or by those having a wing loading (lbs./sq. ft.) times power loading (lbs./HP) of 230 and over. Approaches to such an airport should be clear within a glide path of 30-to-1 in the case of class three and also class four airports, except for instrument landing runways, for which the ratio should be 40-to-1 from a point 4,500 feet from the beginning of the runway.

TABLE 1.—RECOMMENDED AIRPORT DESIGN STANDARDS FOR COMMUNITIES, CITIES AND METROPOLITAN AREAS

TYPE OF COMMUNITY	PLANNING CLASSIFICATION	RECOMMENDED LANDING STRIP LENGTHS, SEA LEVEL CONDITIONS CLEAR APPROACHES*	TYPE OF AIRCRAFT WHICH AIRPORT MAY SAFELY ACCOMMODATE
Small communities not on present or proposed scheduled air carrier system. Includes communities up to a population of approximately 5,000.	1	1,800′ to 2,700′	Small private owner type planes. This includes roughly planes up to a gross weight of 4,000 pounds, or having a wing loading (lbs./sq. ft.) times power loading (lbs./HP) not exceeding 190.
Larger communities located on present or proposed feeder line airways and which have considerable aeronautical activity. General population range 5,000 to 25,000.	2	2,500′ to 3,700′	Larger size private owner type planes and some small size transport planes. This represents roughly planes in the gross weight classification between 4,000 and 15,000 pounds, or having a wing loading (lbs./sq. ft.) times power loading (lbs./HP) of 190 to 230.
Important cities on feeder line airway systems and many intermediate points on the main line airways. General population range 25,000 to several hundred thousand.	3	3,500′ to 4,700′	Present day transport planes. Planes in this classification are represented approximately by those between 10,000 and 50,000 pounds gross weight, or by those having a wing loading (lbs./sq.ft.) times power loading (lbs./HP) of 230 and over.
Cities in this group represent the major industrial centers of the nation and important junction points or terminals on the airways system	4 and 5	4,500′ to 5,700′ 5,700′ and over	Largest planes in use and those planned for the immediate future. This approximately represents planes having a gross weight of 74,000 pounds and over or having a wing loading (lbs./sq.ft.) times power loading (lbs./HP) of 230 and over.

*Approaches shall be clear within a glide path of 20 to 1 from the end of the usable area in the case of Class 1 airports and 30 to 1 in the case of Class 2, 3, 4, and 5 airports except for instrument landing runways for which the ratio shall be 40 to 1.

NOTE.—For scheduled operations of small transport planes 3,000′ is the minimum length recommended at present. For other scheduled operations 3,500′ should be the minimum considered.



Standards by width of landing strips:-

A = 200' (Instrument flying)
B = 150' (Night flying)
C = 100' (Day flying only)

FIG. 1.—REQUIRED LENGTHS OF RUNWAYS AT DIFFERENT ALTITUDES TO CONFORM TO SAFETY STANDARDS OF THE CIVIL AERONAUTICS ADMINISTRATION.

Class III airports are recommended for important cities on feeder line airway systems and many intermediate points on the main line airways. General population range for such a port would be from 25,000 to several hundred thousand. On the other hand, the Civil Aeronautics Administration recommends that major industrial centers and important junction points or terminals on the airways systems have class IV airports.

A class IV airport must have landing strips sufficiently long to give the safety that landing strips 4,700 to 5,700 feet in length would give at the altitude of sea level, for planes having a gross weight of 74,000 pounds and over with a wing loading times power loading ratio of 230 and over.

For scheduled operations of small transport planes, 3,000 feet at sea level is the minimum length recommended by the Civil Aeronautics Administration at present, and for other scheduled operations 3,700 feet at sea level should be the minimum, according to this agency.

The length of landing strips must be lengthened for higher altitudes at the rate of approximately 250 feet for each 1,000 feet above sea level. This is because the atmosphere becomes more rarefied and transport planes need to make a long run in taking-off. A chart has been prepared by the Civil Aeronautics Administration showing the effect of elevation on landing area utility.

The United States by the end of 1944, the Civil Aeronautics Administration reports, will have approximately 600 class IV or better airports, approximately 416 class III airports, approximately 900 class II airports (for planes of the small size transport or larger size private owner type), and approximately 1,213 class I airports (for small private owner type planes up to a gross weight of 4,000 pounds). Altogether these airports total 3,129. They include many built by the Army and Navy which will revert to civil use after the war.

According to former Administrator Stanton, these airports are good —as to size—for many years to come, although additional construction work is needed to make the airports efficient and attractive to the public. For the overwhelming majority of United States cities, Mr. Stanton believes, runways of about 5,000 feet will be adequate for some time to come.

"It must be remembered," he says, "that when you put four motors on a plane instead of two, you increase the safety factor and thereby decrease the amount of runway needed. . . . We believe aircraft designers can turn out planes that will offer greatly improved performance without so increasing their wing-loading as to require enormous increase in runway lengths.

"Increasing the size of the airport probably doesn't increase the number of schedules that can be handled. The bottleneck is the number that can come in and go out under instrument flying conditions. With parallel runways, that is now only about six in and six out in an hour. This is because, under instrument flying, two airplanes cannot be brought down simultaneously unless they can be kept a mile apart laterally. With equipment and procedures we have some prospect of raising that up to 30 in and 30 out within a few years."

These views of former Administrator Stanton are most interesting to students of commercial aviation in Latin America. From these views it would appear that airport facilities in the other Americas, in view of the expansion now under way or planned, will be able to handle the post-war air transport planes without any great difficulty. Thus, with the problem of post-war airport facilities in Latin America presenting no insuperable difficulties, there remains only the problem of trained personnel—for obviously there will be no lack of planes and equipment on the market when war ends.

This problem of manpower—that is, the need in Latin America for skilled pilots, skilled radio men, skilled mechanics, skilled airport administrators, etc.—is being tackled in accordance with the pattern of inter-American economic and technical cooperation adopted at the Third Meeting of American Foreign Ministers at Rio de Janeiro in January, 1942.

Civil aeronautical training in the United States has already been given to 609 young men from the other Americas—484 in 1942 and 125 in 1943—by the United States Department of State and the Civil Aeronautics Administration. A third program has been begun for 148 young men of 11 of the other American republics. The training is from one to two years, and already 351 candidates have been graduated under the first two programs.

The Office of Inter-American Affairs has cooperated in these training programs. It also has sponsored the Inter-American Escadrille, which is an international organization of civil flying clubs having for its purpose the development of Good Neighbor relations by civilians flying between the American republics. To meet the need for meteorologists, the Office of the Coordinator and the United States Weather Bureau jointly sponsored a meteorological school at Medellin, Colombia, where approximately 200 young men of the other American republics received meteorological training.

Consequently, it does not appear that problems of airport facilities, of planes and equipment or of trained personnel are likely to block to any considerable extent the increase of air-borne interchange of people and goods between the Americas after the war. There is no question of the need—and the desire—for this interchange. Our southern neighbors need us, and we need them. They want to visit us, and we want to visit them.

Neither is there any question but what commercial airlines are eager to supply air transportation. As of April 15, 1944, there were, for example, 45 applications pending before the Civil Aeronautics Board for new air services to the Caribbean and Middle and South America.

Air transport, I feel sure, will overcome those natural barriers that in the past have prevented easy access between the United States and the other Americas and, equally important, between and within the other American republics. Our hemisphere's air systems will enable the visitor from Buenos Aires to travel on business or pleasure throughout the United States with utmost ease and facility and speed. Similarly, the traveler from New York will be able to reach Buenos Aires in approximately 24 hours thanks to night-flying in four-engined planes.

In the post-war era when the aspirations of the other Americas for modern air transport can be physically realized, Western Hemisphere airports will continue the development of aviation which has already made the other American peoples the most air-minded of any in the world.

AN UNUSUAL FOUNDATION PROBLEM THE ALUMNI POOL BUILDING

BY DONALD W. TAYLOR*

THE thick buried stratum of soft Blue Clay which exists below large portions of greater Boston is subject to compressions which cause buildings in this district to settle somewhat. Many cities, however, are on sites underlaid by compressible clays. In such localities, so long as foundation designs are restricted to relatively low values of bearing intensity, the settlements which are bound to occur take place in the great majority of cases without endangering the buildings.

The buildings of the Massachusetts Institute of Technology offer interesting examples of settlements. Thus, although this article refers mainly to the Alumni Pool Building, brief mention of settlements of older Technology buildings will first be given. The main group of buildings, completed in 1916, showed settlements ten years after construction which varied from a minimum of about 1 inch at Buildings 1 and 3 to a maximum of about 7 inches at Buildings 2 and 10. Twelve years later (in 1938) the maximum settlement had increased to about 8 inches. The average gross load over the entire area covered by these buildings is about 1500 pounds per square foot and the average net intensity about 800 pounds per square foot. Gross load here refers to the actual building weight; net load to the building weight minus the weight of soil excavated for the foundation.

It actually is differences in settlements and not uniform settlements which cause foundation difficulties. The large differential settlements at this group have been the cause of some plaster cracks and other signs of distortion in the buildings, and have resulted in a certain amount of maintenance expense. This, however, is inevitable in large buildings in such a district. The Technology buildings actually offer a good example of a satisfactory foundation under difficult foundation conditions.

*Assistant Professor of Soil Mechanics, Massachusetts Institute of Technology, Cambridge, Mass.

The main reason for the difference in settlements resides in the variable thickness of a sand layer which overlies the blue clay. The elevation of the surface of this sand varies between 5 and 20 feet below ground surface. The thickness of the sand stratum is over 20 feet where the minimum settlements have occurred, and the buildings are at these locations supported on wooden piles extending a short distance into the sand. Since stresses decrease with depth by spreading outward, much as the intensity of light decreases with the distance from the source, a large thickness of sand leads to stresses on the clay which are relatively small; therefore the settlements which occur are small. At locations of maximum settement the sand stratum is of the order of only four feet thickness, and the foundation consists of wooden piles penetrating the sand and extending well into the clay. The stresses transmitted to the clay are much larger in this case and thus settlements are large. Disturbance of the clay structure by the penetration of piles into it has also contributed to these maximum settlements.

It is interesting to recall certain newspaper articles which appeared when the buildings were new. Settlements of three inches were observed in the first two years and this information was the source of a number of spectacular forecasts. One such forecast stated that readers would live to see about half of the first story disappear below ground. Actually, settlements occur at continuously decreasing rates and if in years to come there is no appreciable change in loading at the Technology site it is probable that additional settlements will not exceed a few inches, even if the buildings remain for hundreds of years.

The Barbour Field House offers a more recent illustration of settlements and demonstrates that settlements occur even when the load is small. This building was constructed on the Technology grounds in 1934. It is founded on caissons of the Gow type, resting on the surface of the sand which at this site varies between 5 and 13 feet in thickness. Fig. 2 illustrates this type of caisson. The building has no basement and the average load intensity over the entire building area is very small. The net intensity of pressure of the caissons on the sand is about 600 pounds per square foot. Settlements at this building have been reasonably uniform and have amounted to about three-quarters of an inch in nine years. During the last two years no appreciable settlement has occurred. Actually, a settlement plug at the corner of this building, which was placed for use in observing settlements, has been used as a bench mark in observing settlements at the Swimming Pool which is but a short distance away.

The Tech Swimming Pool, known as the Alumni Pool, was constructed in 1940 and was also founded on Gow caissons carried to the sand stratum. The foundation plan is shown in Fig. 1, with the por-

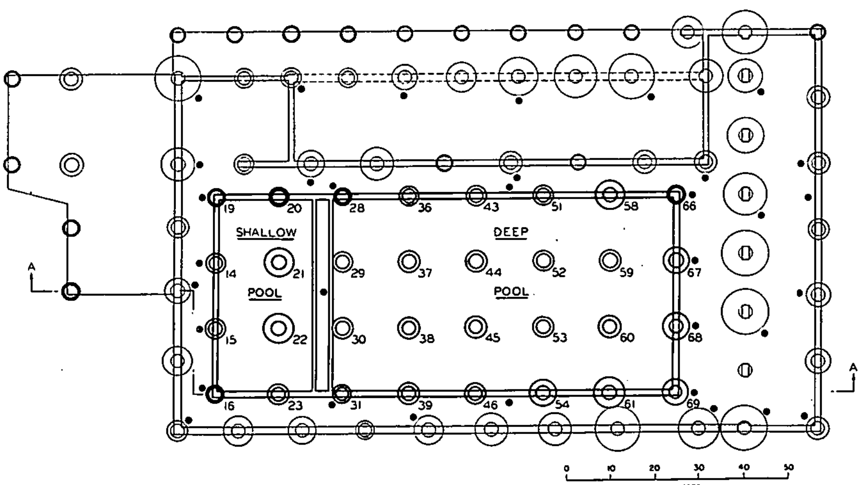


FIG. 1.—PLAN OF BUILDING SHOWING CAISSON LAYOUT; THE POOL SECTION SHOWN BY HEAVY LINES; LOCATIONS OF SETTLEMENT PLUGS SHOWN BY HEAVY DOTS.

tion of the foundation which is below the pool proper shown by heavy lines. Below the pool and below the northeast portion of the building the weight of excavated soil slightly exceeds the building weight; thus in these sections the net load is negative. Below the northeast section of the building there is no appreciable excavation and the net load has a small positive value. The design value of gross loading intensity on the clay below the individual caissons was to be limited, according to original plans, to about 1500 pounds per square foot.

For loads as small as those of this building there would normally be no unusual foundation problem. In this case, however, there was a severe requirement; for proper drainage at the pool curb and for proper appearance of the scum-gutter, practically no differential settlement could be allowed. It therefore was specified that differential settlements of the caissons supporting the pool must not exceed one-quarter inch. Even if the foundation conditions had been uniform and free of horizontal variation, this requirement might have led to considerable concern. As it was, the borings brought to light an unfavorable underground condition; a variable thickness of sand strata was encountered with no thickness of sand whatever at one point at the deep end of the pool. The average depth of sand at the deep end of the pool was only about 2 feet, while at the shallow end the average depth was about 7 feet. This indicated a tendency toward greater settlement at the deep end of the pool, and the danger of differential settlements which might well exceed the very small tolerable limit of one-quarter inch.

A cross section showing the variation in sand thickness at the row of caissons on the side of the pool facing toward Memorial Drive and the Charles River is given in Fig. 2.

It is reported that at this site a few decades ago there was a carriage factory with an adjoining pier. Remains of a pier were encountered in the excavation of the pool. Considerable dredging may have been required for access to this wharf and it appears likely that the area in which no sand existed above the clay may have been the location of the slip to the carriage factory wharf.

The special design which was proposed by the writer and which was used for this building had for its aim the minimizing of differential settlements. The settlements which normally would occur at the deep end of the pool could not be decreased by any practicable procedure, they had to be accepted. It was anticipated that any conventional type of procedure would lead to smaller settlements at the shallow end of the pool. Thus the only course available was a design introducing increased settlements at the shallow end.

Many factors exist which play some part in deciding the magnitude of the settlements which occur, but only two were considered of major importance in this design.

The first factor affecting the settlement is the intensity of load on the surface of the clay. Since it is compression of the clay that causes

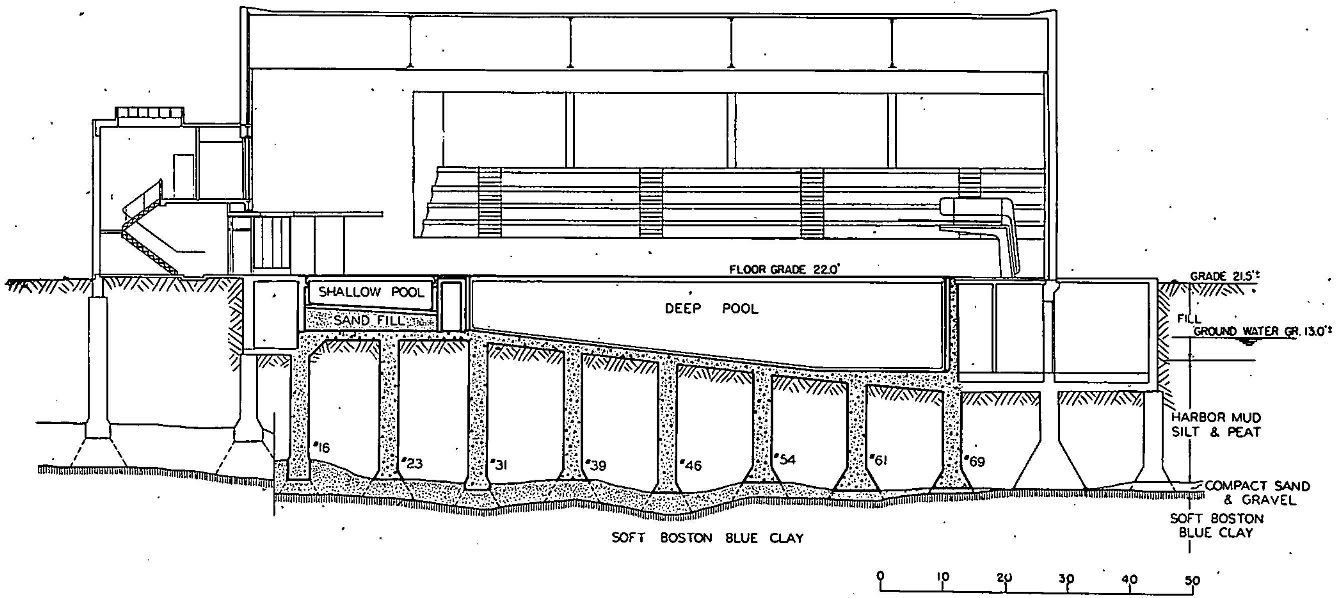


FIG. 2.—LONGITUDINAL SECTION SHOWING THE VARIABLE THICKNESS OF SAND STRATUM ON WHICH THE CAISSONS REST.

the settlements, it is the load on the surface of the clay and not the load on the overlying sand which rules. The effect of loading intensity is demonstrated by typical loading tests and may be expressed as follows: Other things being equal, the settlement under any reasonable loading pressure is approximately proportional to the intensity of pressure.

The second factor affecting settlement is the size of the loaded area. The zone below a loaded area, into which stresses of sensible magnitude are thrown, is sometimes spoken of as a "bulb of pressure." This bulb extends below the loaded area to a depth which is of the order of one to two times the diameter of the loaded area. The depth within which appreciable compressions of the soil occur is the depth of the bulb and this depth is about proportional to the diameter of the loaded area. Thus, other things being equal, the settlement at the surface of a clay stratum, under a given intensity of loading, is proportional to the diameter of the loaded area. In the case of the pool the pressure bulbs to be considered are those for the individual caissons, since there is no appreciable overlapping of these zones. There is no appreciable compression of the clay below these pressure bulbs because there is no net load.

These two factors which affect settlement may be combined into a single relationship worded as follows: For various sizes of loaded areas and various intensities of loading, but with all other conditions remaining constant, the settlement is about proportional to the product of diameter of loaded area and intensity of loading; thus if like settlements are desired, the diameters of the various loaded areas should be made directly proportional to the respective net caisson loads. This relationship was used as the design criterion and in this case the diameter in feet of each bearing area was made equal to 0.15 times the net column load in tons. In this design the net caisson load was assumed to be the design value of column load minus the difference between weight of soil excavated and the weight of caisson concrete within the imaginary vertical cylinder passing through the perimeter of the bearing area at the surface of the clay.

The relationship assumed between the diameter of a bearing area on the clay and the diameter of the base of the caisson where it rests on sand is shown by dotted lines in Fig. 2. The principle used is quite common in foundation design; the effective area subjected to load at any depth below the base of a caisson is assumed to be given approximately by lines from the periphery of the caisson base extending downward and outward at an angle of 30 degrees to the vertical. Once the depth of the sand is known, the desired values of effective bearing diameter on the clay and the diameter of the base of the caisson can be determined by relatively simple computations. The intensity of pressure on the sand was limited to 4 tons per square foot and to obtain diameters meeting this requirement a number of the caissons had to extend well into the sand, as is shown for some of the caissons in Fig. 2. The carrying of the caissons below the sand surface is not at all in line with conventional engineering practice but was one of the details which had to be adopted to cause the required settlements at the shallow end of the pool.

During construction the site was unwatered to below the surface of the sand by pumping from a system of well points. This led to good working conditions during the excavation for the caissons. Each caisson was excavated to sand before its bearing diameter was determined. When sand was reached a careful measurement of the depth of the sand was obtained by sounding to clay with a rod. It then was an easy matter to determine the diameter of the bell, and the depth of excavation into sand when such excavation was required.

Some apprehension was felt regarding the possibility of additional settlement at the Barbour Field House from the drawdown caused by the well point system at the pool. Observations were made relative to the drawdown occurring at the Field House and lines of levels were run for checks on settlements. No settlements of important magnitude occurred at the Field House, however, and the very small settlements which were indicated by the lines of levels were essentially equal at all points.

Some irregularities in settlements of columns are encountered in almost any building on this type of foundation. In order to decrease irregularities as much as possible, the pool was filled with water for a period of about one month before grades for the setting of tile were established. These grades were established on May 1, 1940, and thus the main settlement records commence on that date. It is interesting to note that the differences in settlements at the pool columns showing the maximum and minimum settlements between the first observations, taken on February 12, 1940, and the readings on May 1, amounted to practically one-quarter inch. This is shown on the settlement curves of Fig. 3.

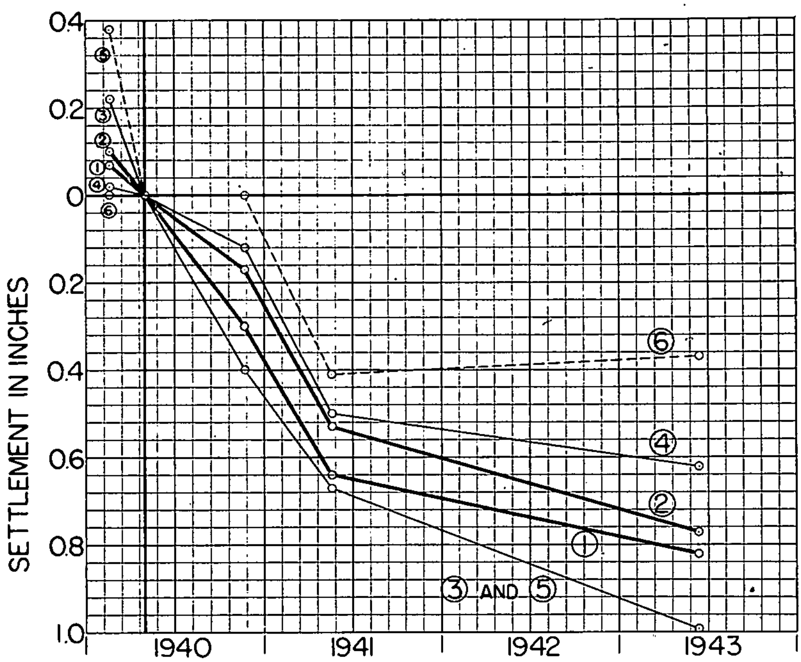


FIG. 3.—SETTLEMENT CURVES; CURVES (1) AND (2) SHOW THE AVERAGE POOL SETTLEMENTS AT THE DEEP END AND THE SHALLOW END RESPECTIVELY, CURVES (3) AND (4) SHOW THE MAXIMUM AND MINIMUM SETTLEMENTS OF THE 13 SETTLEMENT PLUGS AT THE POOL AND CURVES (5) AND (6) SHOW THE MAXIMUM AND MINIMUM SETTLEMENT OF ALL 34 SETTLEMENT PLUGS

Settlement plugs were placed at 34 points, 13 on the pool and 21 outside the pool. Their locations are indicated by heavy dots in Fig. 1. Settlement observations have been made at intervals since the start of construction. Lines of levels were used for these observations and since all level lines were run with care and closed with errors of less than 5 thousandths of a foot, it is believed that the data are in general good to about the nearest tenth of an inch. Differential values undoubtedly have a considerably greater accuracy than this. Fig. 3 is prepared from the settlement observations. Curves are given to show the maximum and minimum of all settlements observed and the maximum and minimum values at the pool proper. The most important curves, however, are those which are shown by heavy lines and which represent average values for the shallow end and the deep end of the pool. Settlement observations were also made in July, 1942. They showed a reasonable check with the results given in Fig. 3 but they are not included because they are not of quite the same precision.

The average settlement in three years since the grades were established is about 0.8 inches. The greatest differential settlement at the pool is between column 28 with a minimum settlement and the point midway between columns 29 and 30 with a maximum settlement; their difference is 0.36 inches. However, other columns differ in settlement by no more than 0.15 inches. This one instance of greater than one-quarter inch settlement is not visible to the eye, and is dismissed as merely an isolated irregularity. The average differential between the two ends of the pool has been slightly greater than 0.1 inch in earlier readings but in the latest series of observations is but 0.05 inch.

A good opportunity is offered here for discussion of a controversial point which often arises when loadings are of the type occurring at the pool; namely, the amounts of settlement occurring when net loads either are negative or have small positive values. It may reasonably be claimed that there should be no settlement if the weight of excavated material is just equal to the weight of a structure itself, and if the building load immediately and exactly replaces the excavated load without disturbance to the subsoil. Even if the weight of the excavated material and the weight of the building are alike, however, the distribution of released stress and the distribution of added stress will differ considerably in most buildings. Also, no building can be constructed fast enough to prevent the occurrence of some upward displacement of the soil during and immediately subsequent to the excavation period, overbalanced later by settlement due to the application of the building weight; the upward displacement may pass unnoticed but not the settlement. In addition, some disturbance to the soil immediately below the bottom of the excavation is inevitable, and in many cases it causes greatly increased settlements. On the other hand, factors sometimes exist which partially counterbalance the above mentioned tendencies toward settlement. For example, at the swimming pool the drawdown of the water table by the well point system must have partially overcome the tendency toward upward displacement during excavation, and it was obvious that surface evaporation occurring at the base of the excavation during the period of caisson construction stiffened the soil and thus gave it greater resistance to compression.

If it were not for the factors discussed above, the pool should show practically no settlement, since the net load is negative. This, moreover, should be the case even if the caissons had been omitted. Actually, however, some settlement must be expected.

The part played by the caissons is statically indeterminate, since factors which have been mentioned make it very difficult to know how much of the pool weight is carried to soil by the caissons and how much by the slab forming the bottom of the pool. The design is based on the assumption that the caissons carry all the load, but undoubtedly some load is carried by the slab. It is important to note that the soil below the pool was in this case so poor that even if there had been no rigid requirements relative to differential settlement it would have been contrary to good engineering practice to have omitted the caissons and merely used a mat foundation. Also, it is believed to be significant that essentially the same average settlements occurred at the pool and outside the pool area where there was no appreciable excavation.

The design method adopted, wherein release of load due to excavation for each caisson was assumed to be only that material above the bearing area of the caisson, appears in this case to be reasonable. When the net load is large, the average settlement often depends mainly on the average net pressure, but when the net load is small as compared to the gross load, the logical choice of the pressures to be used in the design is not so simple.

The essentially uniform settlement of this building has been gratifying. No proof can be given as to what differential settlements would have occurred if special precautions had not been taken. However, it appears probable that the shallow end of the pool would have settled a smaller amount. Had this been the case, the allowable differential of one-quarter inch would without doubt have been exceeded.

The architects for the Swimming Pool Building were Lawrence B. Anderson and Herbert L. Beckwith of the Architectural department of the Institute. The contractor was the Aberthaw Company. The Gow Company was subcontractor for caisson construction. Settlement records during construction were obtained at the writer's request by Mr. D. N. Bates, Resident Engineer for the Aberthaw Company. Settlement observations since the completion of the building have been obtained for the writer by McCreery and Theriault, and by the Sawyer Company, contractors on other Institute buildings in the neighborhood of the Alumni Pool.

FLOW OF WATER IN NETWORK PIPING SYSTEMS

By Edwin B. Cobb, Member* ‡

(Presented at a meeting of the Hydraulics Section, Boston Society of Civil Engineers, held on February 2, 1944)

In 1936 Professor Hardy Cross[1]† first adapted the general method of successive approximations to the problem of determining the flow pattern in network piping systems. He did not go into much detail on the routine work of the method, but presented rather the basic principles which govern the solution, using any of the numerous formulae for flow of fluids in pipes. The method is also applicable to the flow of electricity in conductors. Later in 1936, Professor J. J. Doland[2] applied the method, using the Hazen-Williams formula converted to the form, $h_f=rQ^{1.85}$, and recommending a definite procedure for making and listing the computations. Tables of "r" and $Q^{0.85}$ were presented to simplify the computations. In 1938 Professor Gordon M. Fair[3] showed how to apply the method using the Hazen-Williams Tables or Slide Rule, and suggested simpler methods of listing the computations.

The method described herein is similar except that the Darcy formula,

$$h_f = f\frac{L}{D}\frac{v^2}{2g} \qquad (1)$$

has been substituted for the Hazen-Williams formula, thereby reducing the tedium of the computations without sacrifice of accuracy. This use of the Darcy formula was first suggested by Covil.[4]

Although the Darcy formula is one of the oldest formulae for estimating the friction loss caused by flow in a pipe and its derivation is made a part of most courses in hydraulics, few engineers or waterworks men are skilled in its use. As a part of this paper an attempt has been made to simplify the use of this formula, using the method of Covil[4] and to present test data from published experiments in such

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‡Paper read by Allen J. Burdoin.

†Superior numbers refer to the bibliography at the end of this paper.

form that it may be used as a reliable guide in the selection of the friction factor "f".

From time to time papers are presented describing the use of models for solving network flow problems and theoretically an accurate model should give precise results. Unfortunately few engineers or waterworks men have the money, mechanical ability or the time available to construct satisfactory models for solving such problems. Unless the various elements of the model are based on actual tests made on the corresponding elements of the prototype it is difficult to see how in many instances the results obtained from a model study are superior to those obtained from a mathematical study.

Most network problems are concerned with relatively large discharge at one or two points in a system such as fire flow from hydrants, and in such studies the net effect of many of the secondary loops consisting of the smaller pipe is negligible, and they may be omitted in setting up the problem. Often the domestic consumption on such loops will consume such a large proportion of the flow through them that little is left to add to the discharge under study. The evaluation of the quantity and location of the domestic demand from a network is often most troublesome and requires considerable judgment. In the study of fire flows in small networks such as army posts, the writer has made a practice of considering the total flow, that is fire flow plus domestic demand, as discharging from the hydrants under study.

It should be kept in mind that although the mechanics of balancing the flow is capable of precise results, the accuracy of these results is dependent upon the accuracy with which the pipe friction and the various take-offs are estimated.

Principles of the Solution of Network Flow Problems by Successive Approximations

Let the loop $ABCDEA$, shown in Fig. 1, represent any closed loop of a network with connecting pipes at the points A, B, C, D and E, through which water may enter or leave the circuit.

The solution must fulfill the following conditions:

(1) At any junction, the inflow and the outflow must be equal, or expressed in symbols $\Sigma Q=0$.

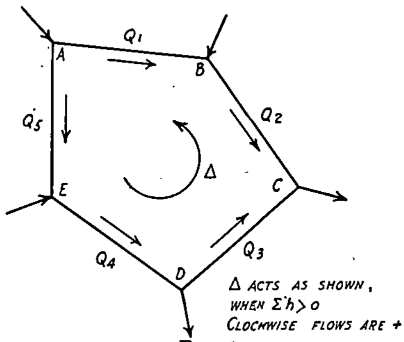


FIG. 1.

(2) The head loss between any two junctions is the same whichever half of the circuit is used to figure it; or, if the head loss is figured all around the circuit proceeding always in the same direction, say clockwise, affixing a + sign to the head loss when proceeding with the flow or "downstream" and a — sign when proceeding against the flow or "upstream", the total head loss must equal zero, or expressed in symbols, $\Sigma h=0$.

The method consists first in assuming a quantity Q flowing in each pipe consistent with condition (1) above. Σh is then computed for each loop, using a friction formula of the general type, $h_f=rQ^x$. In general, Σh will not be equal to zero, and the flow in each loop is corrected by assuming a small circulatory flow Δ set up in each loop, with a rotational direction such that when Σh is computed for the new flows $(Q\pm\Delta)$ the discrepancy between Σh and 0 is reduced. For example, if the head loss is figured in the clockwise direction, and Σh is +, the circulatory flow Δ will flow counterclockwise, so that Δ must be subtracted from all clockwise flows and added to all counterclockwise flows.

It has been shown[1] that

$$\Delta=-\frac{\Sigma rQ^x \text{ (with regard to signs)}}{x\Sigma rQ^{x-1} \text{ (without regard to signs)}} \tag{2}$$

Since $\Sigma rQ^x=\Sigma h$, the minus sign indicates that if Σh is +, proceeding around the loop in the clockwise direction, the circulatory flow Δ will flow counterclockwise, and vice versa. This is equivalent to considering clockwise flows + and counterclockwise flows —.

Σh is computed again for the corrected flows and new corrections Δ computed. This process is repeated until $\Sigma h=0$ (close enough) for each loop. It should be noted that a pipe which is an element of two loops must be corrected for the circulatory flow Δ in each of the two loops of which it is a member.

Use of the Hazen-Williams Formula

The Hazen-Williams formula may be written $h_f=rQ^{1.85}$, and substituting in the formula (2), the corrective approximation becomes

$$\Delta = -\frac{\Sigma rQ^{1.85} \text{ (with due regard to signs)}}{1.85\Sigma rQ^{0.85} \text{ (without regard to signs)}} \tag{3}$$

This is the basis of Doland's method. Fair noted that $rQ^{0.85}=\dfrac{h}{Q}$ and writes the equation as follows:

$$\Delta = -\frac{\Sigma h \text{ (with due regard to signs)}}{1.85\Sigma \dfrac{h}{Q} \text{ (without regard to signs)}} \tag{4}$$

where "h" is obtained by multiplying the unit head loss obtained from the Tables or the Hazen-Williams slide rule by the length of the pipe. In spite of the fact that Fair's equation looks a lot simpler than Doland's there is actually little to choose between them. Some prefer one method and some the other. Both require the use of special tables (or slide rules) throughout the computations.

Use of the Darcy Formula

The Darcy formula (1) may be written

$$h_f = kQ^2 \tag{5}$$

in which "k" is a coefficient equal to JL where

L=length of pipe and

$J=Gf$ in which "f" = friction factor and $G=\dfrac{.0606}{D^5}$ for flows in m.g.d. Hence "k" for any particular pipe is directly proportional to "f" and varies with the Reynold's number Re since "f" varies with Re. If this formula is used

$$\Delta = -\frac{\Sigma kQ^2 \text{ (with regard to signs)}}{2\Sigma kQ \text{ (without regard to signs)}} \tag{6}$$

since $x=2$, and $r=k$.

It may seem at first that the obvious simplification effected by the use of this formula has been purchased at too dear a price, since a fractional exponent has been traded for a variable "k". However, for small changes in Re, "k" may be considered constant within the limits of accuracy with which "k" or "C" may be determined. Even if the original assumption is materially in error, the variation in "k" will usually not be enough to affect the final result, namely the size of pipe to use in the construction or reinforcement of the distribution system. If the original assumption has been a gross error, the values of "k" should be modified following the first correction. In this connection it should be noted that there is much less variation in "f" with "Re" for old pipes that have been in use for a number of years, than is the case with new pipes, and as distribution systems are usually laid out to be adequate for a number of years in the future, this should be taken into account.

The solution of a simple network flow problem is shown in Fig. 2. The steps in the solution are as follows:

(1) Set up a simplified diagram of the system omitting all pipes which do not carry appreciable portions of the flow.

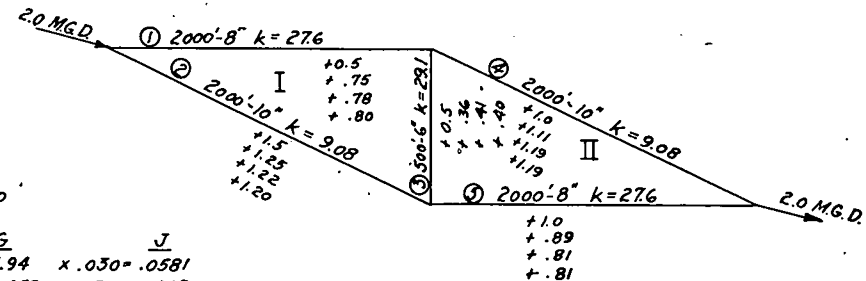
(2) Determine the length, diameter and friction factor for each pipe and from this information determine the k of each pipe. (Tables to facilitate the evaluation of k and a discussion of friction factors are included in this paper.)

(3) Determine the amounts and locations of the inflow and outflow to the network in m.g.d.

(4) Number each pipe and each circuit serially.

(5) Assume the flow in m.g.d. carried by each pipe, noting that the inflow at any junction must equal the outflow. Except with the more complicated systems a plain guess is almost as satisfactory as a careful estimate.

(6) Assign the proper algebraic sign to each of the assumed flows.



$f = .030$

	G		J
6"	1.94	x .030 =	.0581
8"	.459	x .030 =	.0138
10"	.151	x .030 =	.00454

CIR.	PIPE	k	Q	1ST CORRECTION				2ND CORRECTION				3RD CORRECTION				4TH CORRECTION			
				kQ	kQ^2	Δ_1	Q_1	kQ_1	kQ_1^2	Δ_2	Q_2	kQ_2	kQ_2^2	Δ_3	Q_3	kQ_3	kQ_3^2	Δ_4	Q_4
I	1	27.6	+0.5	13.8	+6.9	+.248	+.75	20.7	+15.5	+.028	+.78	21.5	+16.8	+.018	+.80				
	2	9.08	-1.5	13.6	-20.4	+.248	-1.25	11.3	-14.2	+.028	-1.22	11.0	-13.5	+.018	-1.20				
	3'	29.1	-0.5	14.6	-7.3	+.248-.108	-.36	10.5	-3.8	+.028-.076	-.41	11.9	-4.9	+.018-.004	-.40				
				42.0	-20.8			42.5	-2.4			44.4	-1.6						
				84.0		-.248		85.0		-.028		88.8		-.018					
II	3^2	29.1	+0.5	14.6	+7.3	+1.08-.248	+.36	10.5	+3.8	+.076-.028	+.41	11.9	+4.9	+.004-.018	+.40				
	4	9.08	+1.0	9.1	+9.1	+1.08	+1.11	10.1	+11.2	+.076	+1.19	10.8	+12.8	+.004	+1.19				
	5	27.6	-1.0	27.6	-27.6	+1.08	-.89	24.6	-21.9	+.076	-.81	22.4	-18.1	+.004	-.81				
				51.3	-11.2			45.2	-6.9			45.1	-0.4						
				102.6		-.108		90.4		-.076		90.2		-.004					

Friction From Inlet to Outlet

Line	k	Q	kQ^2
1	27.6	.80	17.6
4	9.08	1.19	12.8
			30.4 ft.
2	9.08	1.20	13.0
5	27.6	.81	18.0
			31.0 ft.

FIG. 2.—BALANCING COMPUTATIONS.

(a) Clockwise flow in a circuit ↷ or from left to right in a line → is called positive (+).
(b) Counterclockwise flow in a circuit ↶ or from right to left in a line ← is called negative (—).

For convenience it appears best to place the flow figures under each line and then have the sign represent the direction of the flow in the line only.

(7) Set up the tabular form as illustrated and fill in the circuit and pipe numbers and the respective k and Q values being sure to assign to Q the proper sign, clockwise flow in the circuit being +, and counterclockwise —.

(8) Solve for kQ and kQ^2.

This is done most simply on the polyphase slide rule in the following manner:

(a) Set the 1 on the B scale on the value of k on the A scale. Move the index to the value of Q on the B scale and read the value of kQ on the A scale.

(b) With the 1 on the B scale as before, move the index to the value of Q on the C scale and read the value of kQ^2 on the A scale.

(9) Disregard the signs for the kQ's and add the results for each circuit and multiply by 2.

(10) The signs of the kQ^2's are the same as their respective Q's. Add the kQ^2's algebraically for each circuit.

(11) Divide the sum of the kQ^2's by the doubled sum of kQ's and give the result the proper sign. This is $-\Delta$.

(12) List the Δ's in their column against each pipe in the circuit. Where a pipe appears in two circuits the Δ for each of the circuits should be listed, but the carry-over from the second circuit should have its sign changed.

(13) Obtain the Q_1 values by adding algebraically the Δ's to their respective Q's. This completes the first correction.

(14) List the Q_1's under their respective pipes, giving them their correct signs and check the inflow and outflow at each junction. Where slight errors are found in the last significant figure, adjust the flows to give perfect agreement.

It is important that the flows balance at each junction, otherwise the solution will not converge.

(15) Using the original k's and the corrected Q's carry out the cycles of the second and subsequent corrections.

(16) After repeating the corrections until the changes become of small magnitude, compute the total friction from the inlet to the outlet by two different paths using the corrected flows and the k values for each pipe, and compare the results. If a satisfactory arrangement of the flows has been reached the friction should be the same by either route.

For problems involving pipe from 6 inches to 24 inches in size the use of flows in m.g.d. gives the most convenient numbers to handle. For problems involving large size pipe flows in c.f.s. could also be used conveniently, but for smaller pipe the use of flows in g.p.m. would probably be better. It should be remembered, however, that the value of k will depend on the units used, as well as on the diameter of the pipe.

To indicate the advantages of the method described, in com-

Net Work					Trial Conditions					1st Correction
Circuit No.	Pipe No.	Length 1,000 ft.	Diam. in.	C	Q m.g.d.	S 1/1000	h ft.	$\frac{h}{Q}$	Δ m.g.d.	Q m.g.d.
I . . .	1	2.0	12	120	+0.6	0.58	+1.16	1.93	-.015. . . .	+0.585
	2	0.5	6	120	+0.3	4.70	+2.35	7.83	-.015+.007	+0.292
	3	0.5	8	100	-0.4	2.76	-1.38	3.45	-.015	-0.415
	4	2.0	8	100	-0.2	0.77	-1.54	7.70	-.015+.006	-0.209
							+0.59	20.91		

$$-\Delta = \frac{+0.59}{20.91 \times 1.85} = +0.015$$

Typical Computations for Method of Equivalent Pipe Size

Net Work					Trial Conditions				1st Correction
Circuit No.	Pipe No.	Length, ft.	Diam. in.	Equiv. 8" pipe length	Q g.p.m.	h ft.	$\frac{1.85h}{Q}$	Correction g.p.m. Δ	Q g.p.m.
I . . .	1	970	12	135	+1700	+10.6	0.012	-32	+1668
	2	370	6	1500	+300	+4.8	0.030	-32 -97	+171
	21	2150	8	2226	-400	-12.2	0.057	-32	-432
	22	550	12						
						+ 3.2	0.099		

$$-\Delta = \frac{+3.2}{.099} = 32$$

FIG. 3.—TYPICAL COMPUTATIONS FOR METHODS OF PROF. G. M. FAIR (ABOVE) AND FOR METHOD OF EQUIVALENT PIPE SIZES (BELOW).

parison with other methods, Fig. 3 has been prepared, which shows a portion of the bookkeeping systems employed in Fair's method and in the method which employs equivalent pipe sizes. Let it be remembered that in the writer's method but two simple slide rule operations are necessary to calculate kQ and kQ^2.

In Fair's method, unless one has a Hazen-Williams slide rule it is first necessary to determine the unit head loss from a table which may require a certain amount of interpolation. Next, the total head loss must be determined by multiplying the unit loss by the length; after which the $\frac{h}{Q}$ values must be determined by dividing the total head losses by the flows. Finally the sum of the $\frac{h}{Q}$'s must be multiplied by 1.85.

The method which employs equivalent 8-inch pipe lengths was devised to simplify the computations through the use of specially prepared tables or charts. Unless a considerable number of tables or charts are provided to cover the possible range of friction factors the application of the system is somewhat limited. If tables are used, considerable interpolation may be necessary and if large pipes are involved they become quite voluminous; furthermore, the values are expressed as unit values which must be multiplied by the lengths to get the actual values. The use of charts permits the elimination of the interpolation and multiplying, but the writer has found their use extremely tiring to the eyes, because of the multiplicity of lines crossing at flat angles.

It is believed that at least one-third less time is required for the computations by the writer's method as compared with either of the other two methods with which it is compared.

A second advantage of the use of the Darcy formula, as pointed out by Covil,[4] lies in the ease with which parallel lines, various sizes of pipe in series, or the losses in fittings and valves, may be expressed in terms of a single equivalent value of k. Figure 4 indicates how the equivalent values of k may be determined.

VALUE OF k_s FOR FITTINGS, VALVES, ETC. Figure No 4.

$$H_f = K\frac{v^2}{2g} = K\frac{Q^2}{2gA^2} = k_s Q^2 \qquad k_s = \frac{K}{2gA^2} = K\frac{1}{2gA^2}$$

Pipe Diam. (ins.)	Q in MGD $k_s = K\frac{1}{26.9A^2}$	Q in CFS $k_s = K\frac{1}{64.4A^2}$	Q in GPM $k_s = K\frac{1}{13,000,000A^2}$
4	4.88 K		
5	2.01 K		
6	.965 K		
8	.305 K		
10	.125 K		
12	.0600 K		
14	.0325 K		
15	.0246 K		
16	.0190 K		
18	.0118 K		
20	.00780 K		
24	.00375 K		
30	.00154 K		
36	.000742 K		
42	.000400 K		
48	.000235 K		

PIPE OR FITTINGS IN SERIES

$$H_f = k_1 Q^2 + k_2 Q^2 + k_s Q^2 ---- + k_n Q^2$$
$$H_f = (k_1 + k_2 + k_s ---- k_n) Q^2$$
$$H_f = k_T Q^2$$

PARALLEL PIPE LINES

A single coefficient k_e may be found for two pipe lines in parallel having common inlets and outlets

$$H_f = k_e Q^2 \quad \text{or} \quad Q = \frac{\sqrt{H_f}}{\sqrt{k_e}} \quad \text{and} \quad Q = \frac{\sqrt{H_f}}{\sqrt{k_A}} + \frac{\sqrt{H_f}}{\sqrt{k_B}}$$

$$\frac{\sqrt{H_f}}{\sqrt{k_e}} = \frac{\sqrt{H_f}}{\sqrt{k_A}} + \frac{\sqrt{H_f}}{\sqrt{k_B}} \quad \text{divide by } \sqrt{H_f} \quad \frac{1}{\sqrt{k_e}} = \frac{1}{\sqrt{k_A}} + \frac{1}{\sqrt{k_B}}$$

$$k_e = \frac{1}{\left(\frac{1}{\sqrt{k_A}} + \frac{1}{\sqrt{k_B}}\right)^2}$$

To Solve Using Polyphase Slide Rule
1) Set index slider over 1 on D scale and set k_A on B scale under hair line on index, read result on D scale under 1 on C scale.
2) Repeat for k_B.
3) Add results of steps 1 and 2.
4) Set sum from step 3 on C scale under line on index, read value of k_e on A scale under 1 on B scale.

FIG. 4.

THE DARCY FORMULA

The Darcy formula has two advantages, namely a dimensionless friction coefficient and an exponent of the velocity term, which is a whole number. It also has two disadvantages which appear to hinder its general use by engineers and waterworks men: first, in the usual form it is not convenient for rapid use, and second the evaluation of the friction factor for everyday use does not seem to have been given much study. In general, most friction formulae have been greatly overshadowed by the popular Hazen and Williams formula which, because of the handy form of its tables and slide rule, is almost universally used by engineers and waterworks men.

The writer believes that had equally convenient tables been proposed, based on the Darcy formula, it would now occupy an equally popular position. A simple table listing the values of G for various pipe sizes would go a long way toward making the formula one of the most convenient to use. Such a tabulation is given in Table I for all pipes from ¼-inch to 120-inch diameter for flows in m.g.d., c.f.s. and g.p.m. Table II gives values of G for cast iron pipe from 4-inch to 18-inch diameter, for various thicknesses of lining for flow in m.g.d. Note that the thickness of the lining has a considerable effect on the friction loss, especially in the smaller sizes. Values of J for unlined pipe are given in Table III for various values of "f".

Too often the limitations of Hazen and Williams C are overlooked and it is forgotten that with the rougher pipes results can be considerably in error. A plot of the Darcy friction factor f against Reynold's number gives a simple picture of the variation of the coefficient for various pipes and because both are dimensionless it can be used universally. If one were to have such a plot on which the available data from actual tests were shown he could quickly see upon how much data his estimate of the friction factor was based and could also obtain a fair idea of what the possible error in his calculations might be. A number of such plots based upon data gleaned from engineering literature are appended to this paper as Figures 6, 7, 8, 9 and 10. That the data are by no means complete is recognized and the writer regrets that time was not available to gather more data.

The term Reynold's number is a "bugaboo" to many engineers, due principally to the fact that they are not familiar with the use of viscosity. To simplify this problem the writer has prepared a nomograph (Fig. 5) from which one can determine Reynold's number easily, having given the pipe diameter, the water temperature and the quantity flowing.

TABLE I

Inside diameter of pipe, in.	Value of G		
	Q in m.g.d.	Q in c.f.s.	Q in g.p.m.
	$G=\frac{.0606}{D^5}$	$G=\frac{.0253}{D^5}$	$G=\frac{.000000125}{D^5}$
¼			32.1
½			0.991
¾			0.131
1			0.0248
1¼			0.0109
1½			0.00410
1¾			0.00190
2	471.0	196.	0.000970
2½	154.0	64.5	0.000319
3	62.0	25.9	0.000128
4	14.8	6.18	0.0000305
5	4.82	2.01	0.00000995
6	1.94	0.810	0.00000400
8	0.459	0.192	0.000000947
10	0.151	0.0630	
12	0.0606	0.0253	
14	0.0281	0.0117	
15	0.0199	0.00829	
16	0.0144	0.00601	
18	0.00798	0.00333	
20	0.00470	0.00196	
21	0.00369	0.00154	
24	0.00189	0.000791	
30	0.000620	0.000259	
36	0.000249	0.000104	
42	0.000115	0.0000482	
48	0.0000592	0.0000247	
54	0.0000328	0.0000137	
60	0.0000194	0.00000810	
66	0.0000120	0.00000503	
72	0.00000779	0.00000325	
84	0.00000360	0.00000150	
96	0.00000185	0.000000772	
108	0.00000103	0.000000428	
120	0.000000606	0.000000253	

TABLE II.—VALUES OF G (Flows in m.g.d.)

Nominal inside diameter of pipe	Unlined pipe	Lined Pipe—Thickness of Lining (in.)								Nominal inside diameter of pipe
		1/32	1/16	3/32	1/8	5/32	3/16	7/32	1/4	
4	14.8	15.9	17.3	18.7	20.3	22.1	24.1	26.3	28.7	4
6	1.94	2.04	2.15	2.27	2.40	2.53	2.68	2.83	2.99	6
8	0.429	0.478	0.497	0.518	0.539	0.548	0.584	0.609	0.635	8
10	0.151	0.156	0.161	0.166	0.171	0.177	0.182	0.189	0.195	10
12	0.0606	0.0622	0.0638	0.0655	0.0673	0.0691	0.0710	0.0729	0.0749	12
14	0.0281	0.0286	0.0293	0.0300	0.0306	0.0313	0.0320	0.0327	0.0336	14
16	0.0144	0.0147	0.0149	0.0152	0.0156	0.0159	0.0162	0.0165	0.0169	16
18	0.00798	0.00811	0.00825	0.00842	0.00856	0.00871	0.00885	0.00901	0.00919	18

TABLE III.—VALUES OF J (Unlined Pipe)
(Flows in m.g.d.)

Nominal* diam. of pipe	G	$f=$ .0150	$f=$ .0175	$f=$ .0200	$f=$ .0225	$f=$ .0250	$f=$ .0275	$f=$ .0300	$f=$ .0325	$f=$ .0350	$f=$ .0400
4	14.8	.221	.258	.295	.332	.368	.405	.442	.480	.518	.590
6	1.94	.0290	.0339	.0387	.0435	.0485	.0532	.0581	.0629	.0678	.0775
8	.459	.00688	.00803	.00918	.0103	.0115	.0126	.0138	.0149	.0161	.0184
10	.151	.00227	.00265	.00304	.00340	.00379	.00416	.00454	.00492	.00530	.00605
12	.0606	.000912	.00106	.00122	.00137	.00152	.00168	.00182	.00198	.00213	.00244
14	.0281	.000421	.000491	.000561	.000631	.000702	.000772	.000842	.000915	.000985	.00113
16	.0144	.000216	.000252	.000288	.000324	.000360	.000396	.000432	.000469	.000502	.000575
18	.00798	.000120	.000140	.000160	.000179	.000199	.000219	.000239	.000259	.000279	.000319
20	.00470	.0000708	.0000825	.0000942	.000106	.000118	.000130	.000141	.000153	.000165	.000188
24	.00189	.0000284	.0000331	.0000378	.0000425	.0000472	.0000520	.0000568	.0000615	.0000662	.0000756

$J=Gf$.
*Inside.

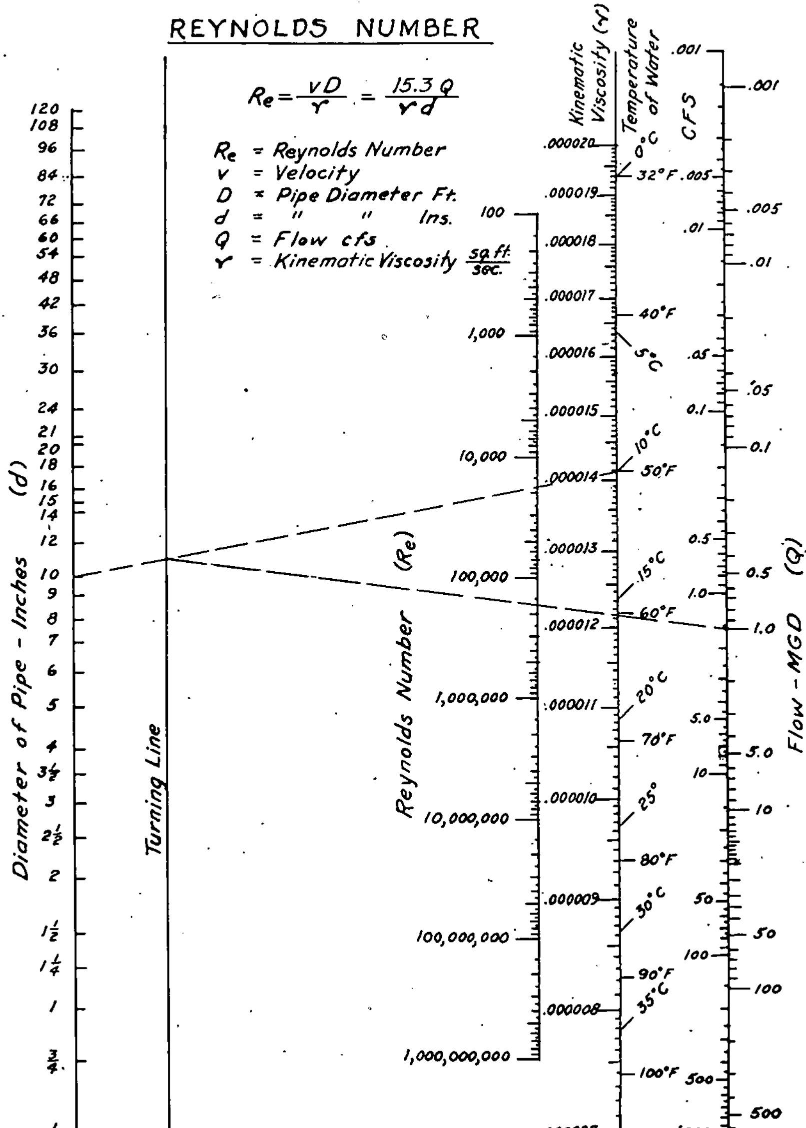

REYNOLDS NUMBER
$R_e = \frac{vD}{\gamma} = \frac{15.3\,Q}{\gamma d}$
R_e = Reynolds Number
v = Velocity
D = Pipe Diameter Ft.
d = " " Ins.
Q = Flow cfs
γ = Kinematic Viscosity $\frac{sq.ft.}{sec.}$
Diameter of Pipe - Inches (d)
Turning Line
Reynolds Number (R_e)
Kinematic Viscosity (γ)
Temperature of Water
CFS
Flow - MGD (Q)

FIG. 5.

Since most of the available data on pipe friction are expressed in terms of Hazen and Williams' C, an attempt has been made to show the relation between f and C. If the Darcy Formula is equated with the Hazen and Williams formula and f is solved for in terms of C, we obtain

$$f = \frac{193.2}{C^{1.85} D^{0.16} V^{0.15}} \tag{7}$$

in which f = friction factor in the Darcy formula

C = coefficient in the Hazen and Williams formula

D = diameter of pipe in feet

V = velocity of flow in feet per second.

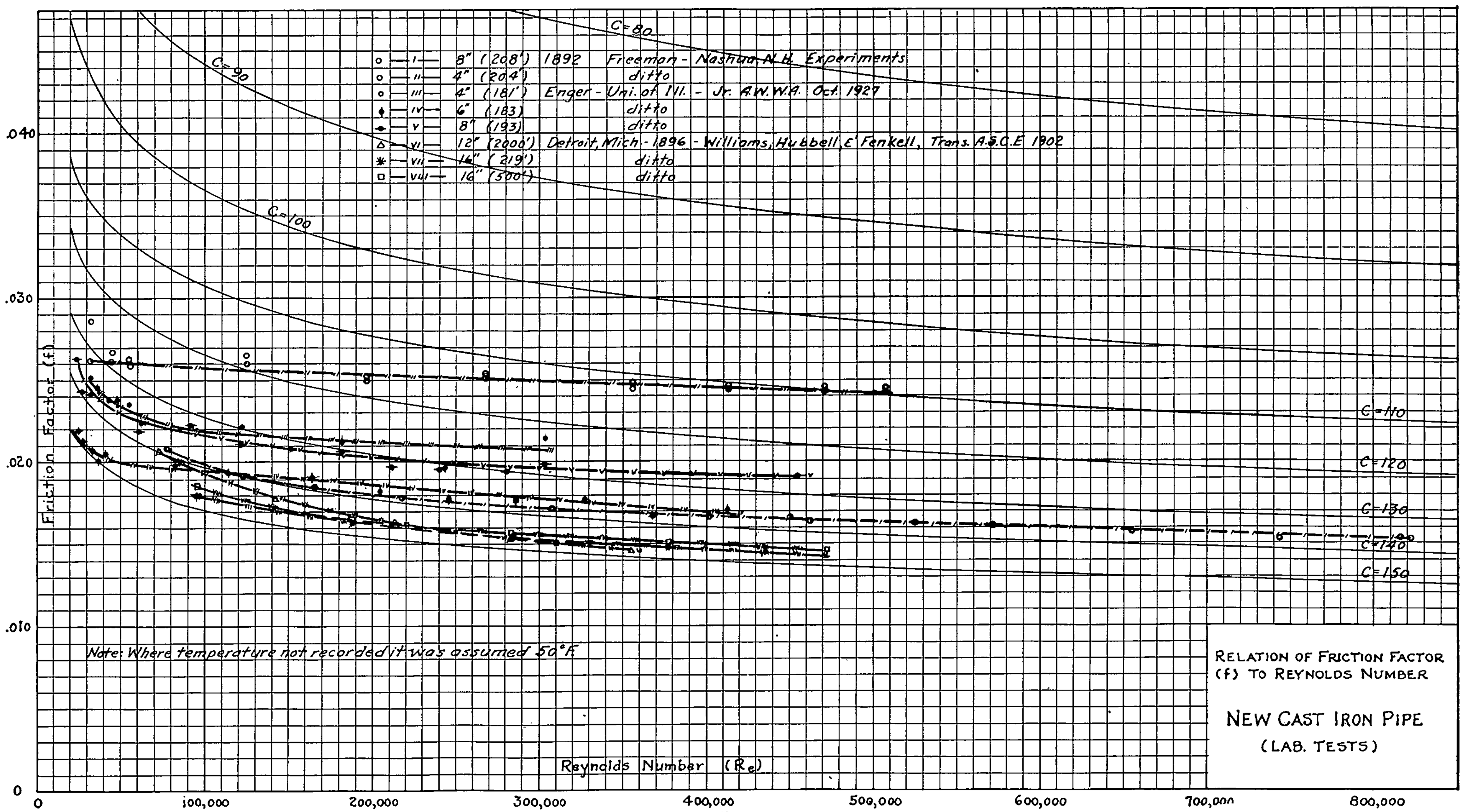
On Figures 6 to 10, curved lines have been plotted corresponding to different values of Hazen-Williams "C" using an assumed water temperature of 50° F. These lines should be quite helpful to those who might wish to select a value of "f" for use with the writer's method corresponding as closely as practicable to some value of "C". For the relatively smooth pipe Hazen and Williams' C conforms to the data extremely well, but with the rougher pipes the error becomes quite marked.

It will be noted that an arithmetic scale is used in Figs. 6 to 10 instead of the more usual logarithmic plotting. This was done because the writer feels that this plotting gives a truer picture of the variation.

In using the formula for solving network problems f is taken as constant for any one pipe. It is evident that for rough pipes or with high velocities this practice gives fairly accurate results; with the smoother pipe and lower velocities some error is evident. Fortunately, however, under these conditions the head losses are smaller and generally do not affect the result greatly. In any event some judgment must be used and, if necessary, changes in the value of f may be made if conditions appear to warrant it.

For those who have been using the Manning formula the following relationship may be of assistance in evaluating the friction factor f. When the Manning formula is equated to the Darcy formula and f solved for in terms of n the result is as follows:

$$f = \frac{186\, n^2}{D^{1/3}} \tag{8}$$



C=80
C=90
C=100
C=110
C=120
C=130
C=140
C=150
I 8" (208') 1892 Freeman - Nashua, N.H. Experiments
II 4" (204') ditto
III 4" (181') Enger - Uni. of Ill. - Jr. A.W.W.A. Oct. 1927
IV 6" (183) ditto
V 8" (193) ditto
VI 12" (2000') Detroit, Mich - 1896 - Williams, Hubbell & Fenkell, Trans. A.S.C.E 1902
VII 16" (219') ditto
VIII 16" (500') ditto
Friction Factor (f)
.040
.030
.020
.010
0
Reynolds Number (Re)
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
Note: Where temperature not recorded it was assumed 50°F.
RELATION OF FRICTION FACTOR (f) TO REYNOLDS NUMBER
NEW CAST IRON PIPE
(LAB. TESTS)

FIG. 6.

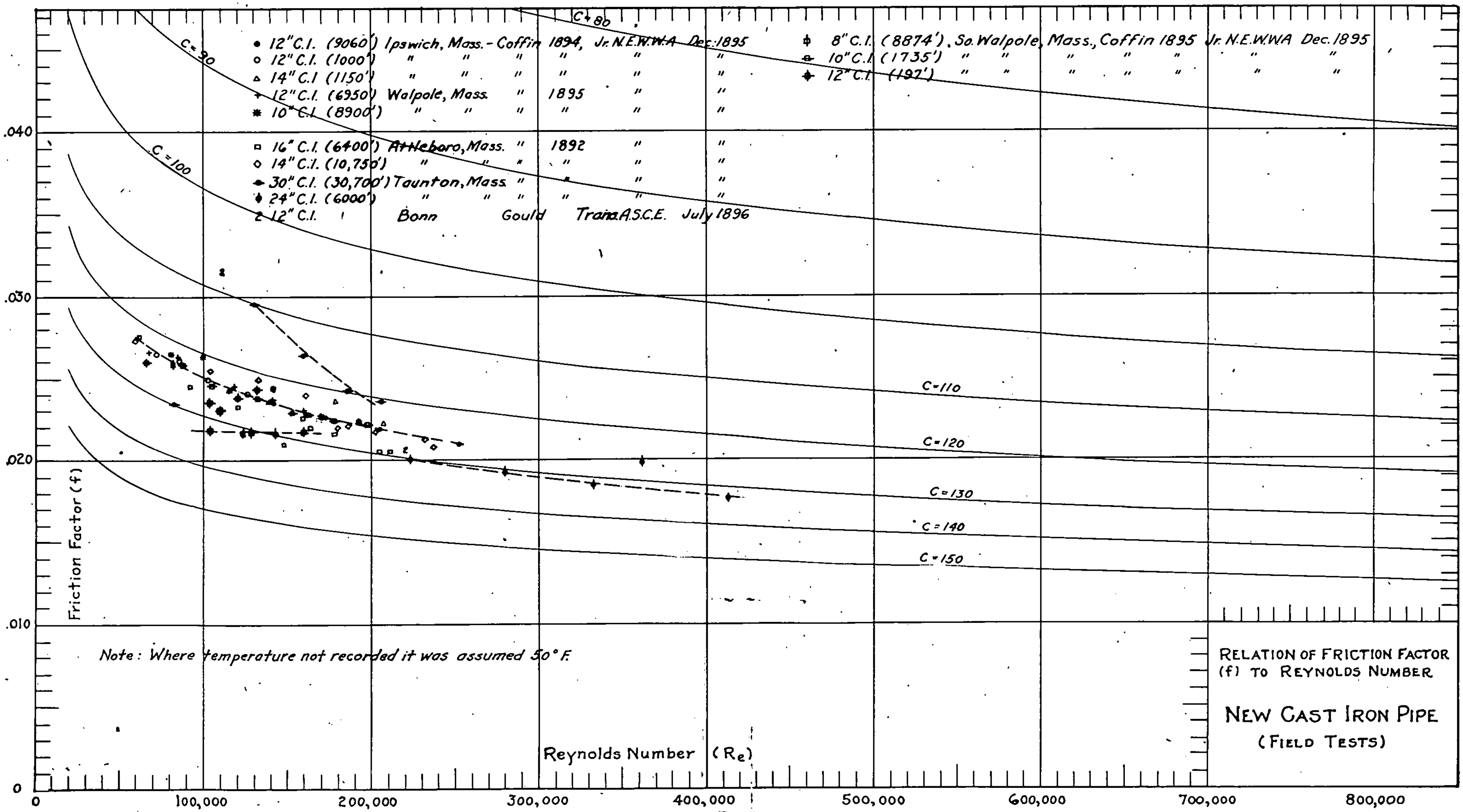
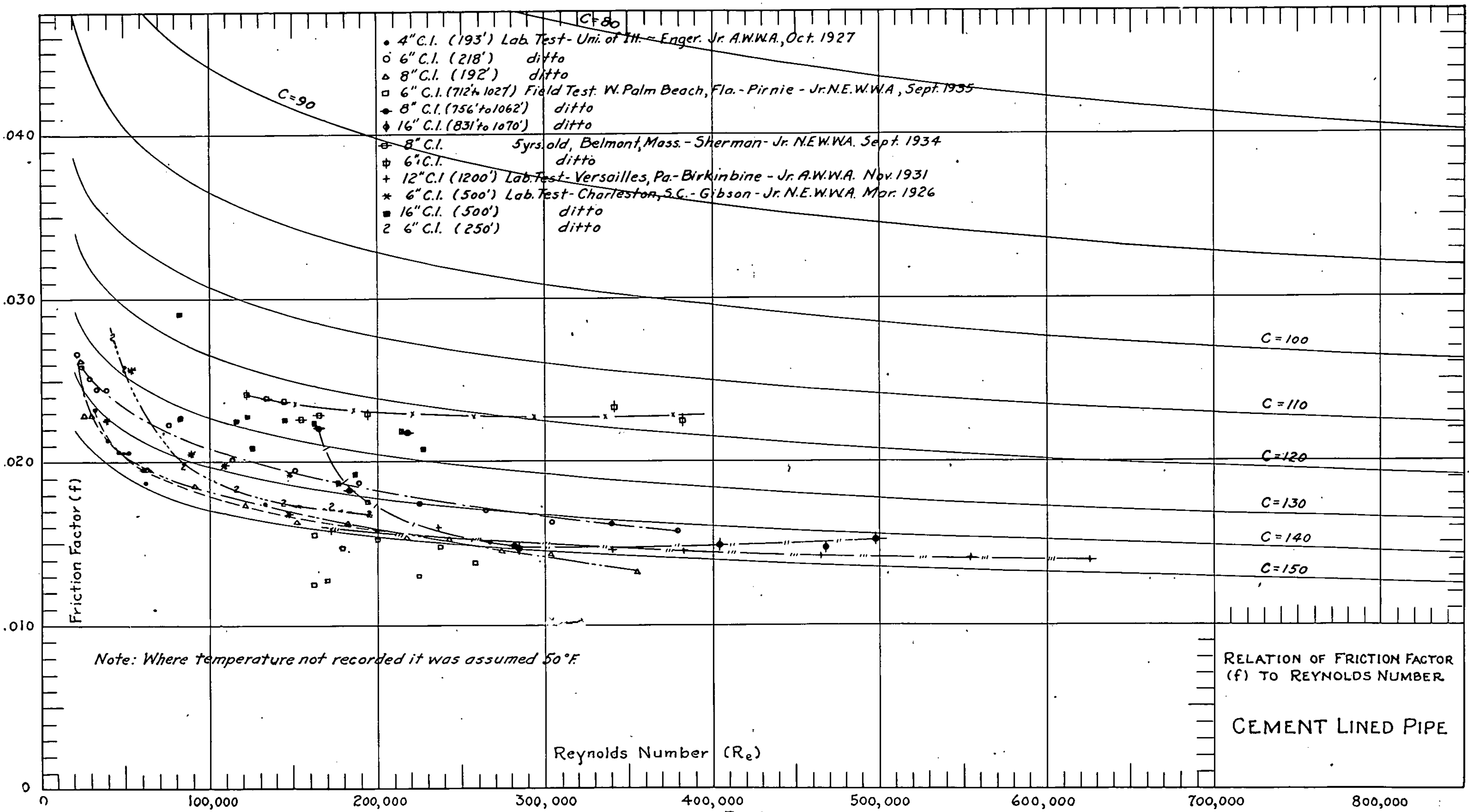

12" C.I. (9060') Ipswich, Mass. - Coffin 1894, Jr. N.E.W.W.A. Dec. 1895
12" C.I. (1000') " " " " " "
14" C.I. (1150') " " " " " "
12" C.I. (6950') Walpole, Mass. " 1895 " "
10" C.I. (8900') " " " " " "
16" C.I. (6400') Attleboro, Mass. " 1892 " "
14" C.I. (10,750') " " " " " "
30" C.I. (30,700') Taunton, Mass. " " " "
24" C.I. (6000') " " " " " "
12" C.I. Bonn Gould Trans. A.S.C.E. July 1896
8" C.I. (8874') So. Walpole, Mass., Coffin 1895 Jr. N.E.W.W.A. Dec. 1895
10" C.I. (1735') " " " " " " " "
12" C.I. (197') " " " " " " " "
C = 80
C = 90
C = 100
C = 110
C = 120
C = 130
C = 140
C = 150
.040
.030
.020
.010
0
Friction Factor (f)
Note: Where temperature not recorded it was assumed 50° F.
Reynolds Number (Re)
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
RELATION OF FRICTION FACTOR (f) TO REYNOLDS NUMBER
NEW CAST IRON PIPE
(FIELD TESTS)

FIG. 7.



C=80
C=90
C=100
C=110
C=120
C=130
C=140
C=150
• 4" C.I. (193') Lab. Test - Uni. of Ill. - Enger. Jr. A.W.W.A., Oct. 1927
o 6" C.I. (218') ditto
△ 8" C.I. (192') ditto
□ 6" C.I. (712' to 1027') Field Test. W. Palm Beach, Fla. - Pirnie - Jr. N.E.W.W.A., Sept. 1935
8" C.I. (756' to 1062') ditto
16" C.I. (831' to 1070') ditto
8" C.I. 5 yrs. old, Belmont, Mass. - Sherman - Jr. N.E.W.W.A. Sept. 1934
6" C.I. ditto
+ 12" C.I. (1200') Lab. Test - Versailles, Pa. - Birkinbine - Jr. A.W.W.A. Nov. 1931
* 6" C.I. (500') Lab. Test - Charleston, S.C. - Gibson - Jr. N.E.W.W.A. Mar. 1926
■ 16" C.I. (500') ditto
2 6" C.I. (250') ditto
Friction Factor (f)
.040
.030
.020
.010
0
Note: Where temperature not recorded it was assumed 50°F.
Reynolds Number (Re)
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
Relation of Friction Factor (f) to Reynolds Number
Cement Lined Pipe

FIG. 8.

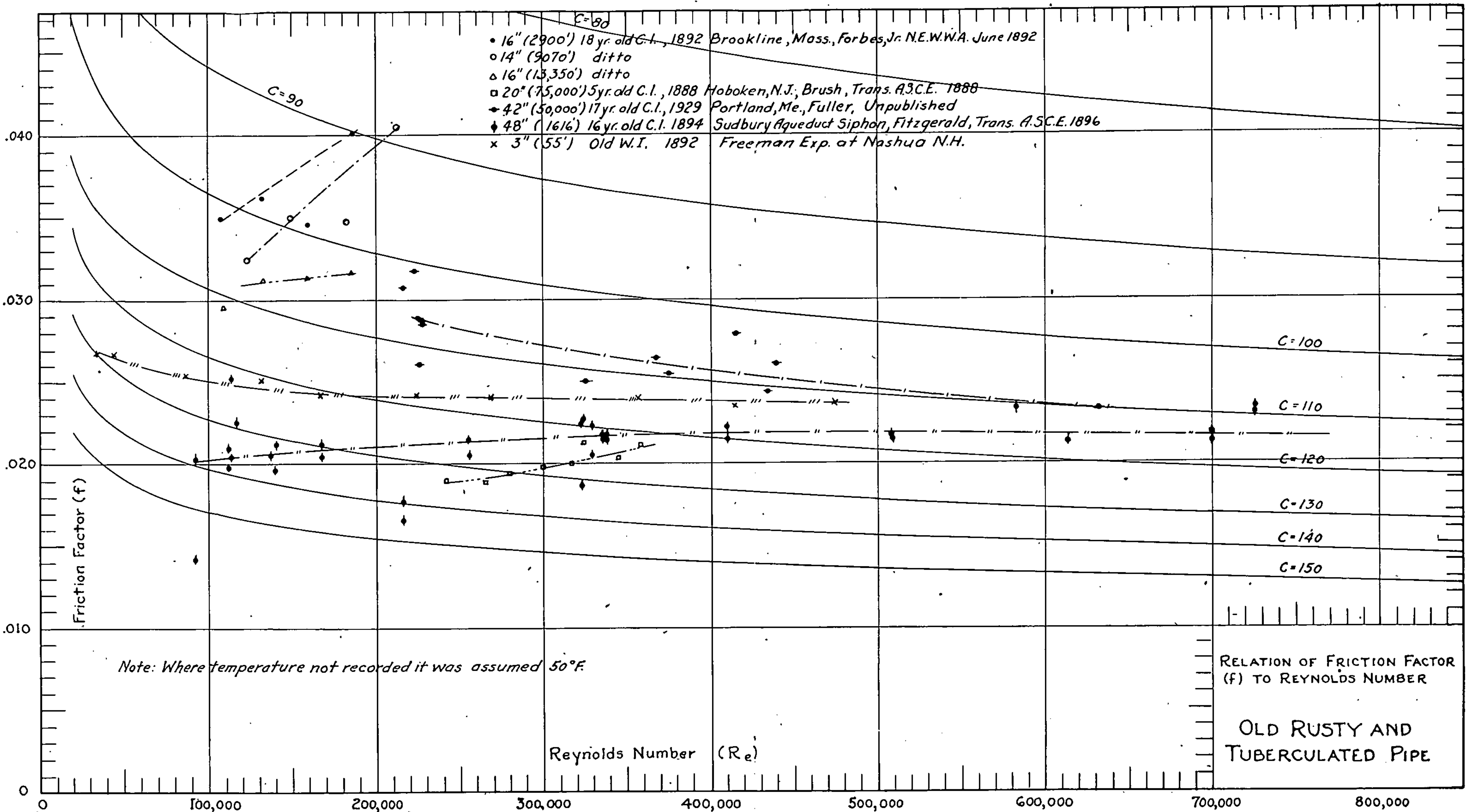
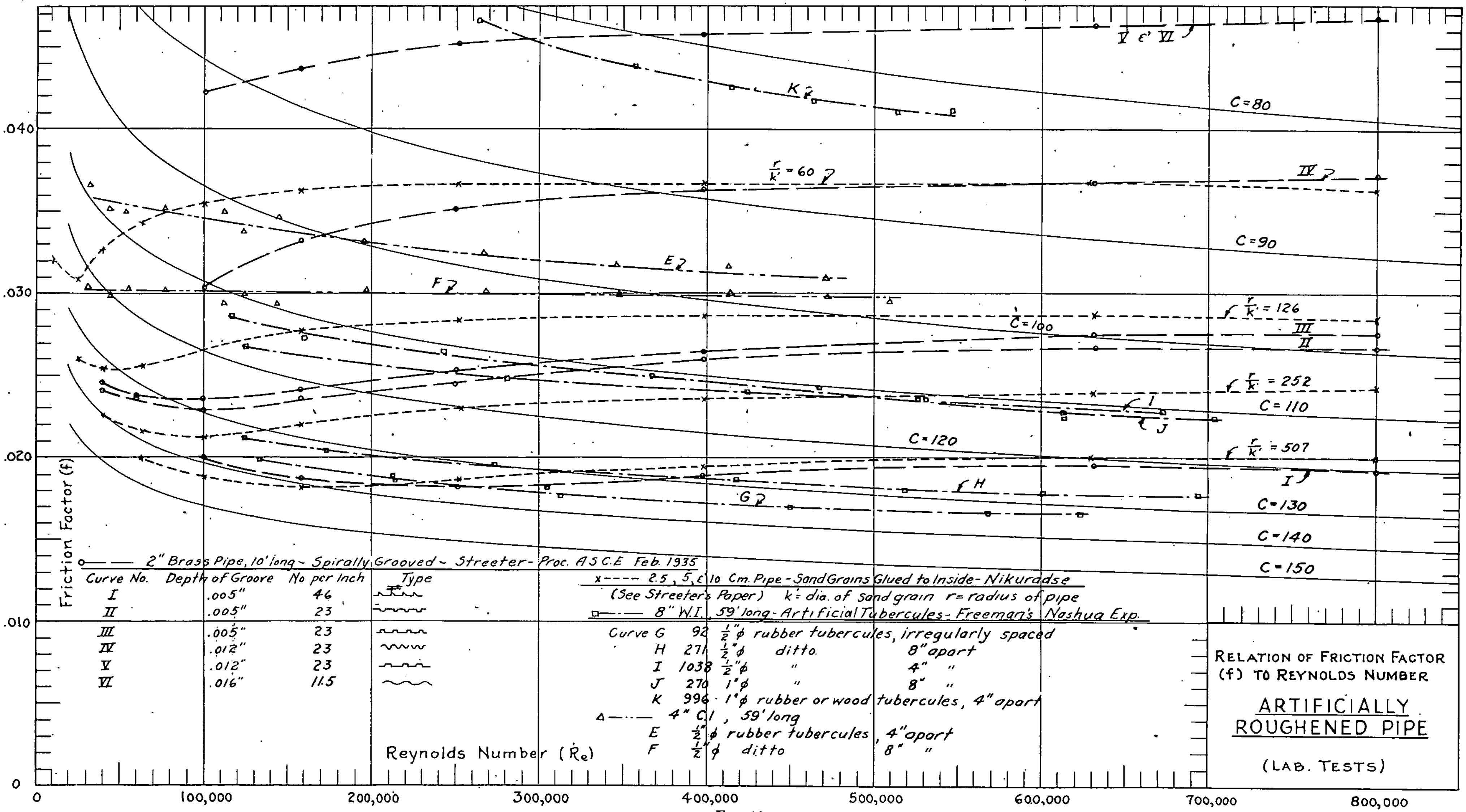

C=80
C=90
C=100
C=110
C=120
C=130
C=140
C=150
• 16" (2900') 18 yr. old C.I., 1892 Brookline, Mass., Forbes, Jr. N.E.W.W.A. June 1892
○ 14" (9070') ditto
△ 16" (13,350') ditto
□ 20" (75,000') 5 yr. old C.I., 1888 Hoboken, N.J.; Brush, Trans. A.S.C.E. 1888
42" (50,000') 17 yr. old C.I., 1929 Portland, Me., Fuller, Unpublished
48" (1616') 16 yr. old C.I. 1894 Sudbury Aqueduct Siphon, Fitzgerald, Trans. A.S.C.E. 1896
× 3" (55') Old W.I. 1892 Freeman Exp. at Nashua N.H.
.040
.030
.020
.010
0
Friction Factor (f)
Note: Where temperature not recorded it was assumed 50°F.
Reynolds Number (Re)
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
Relation of Friction Factor (f) to Reynolds Number
Old Rusty and Tuberculated Pipe

Fig. 9.



Friction Factor (f)
Reynolds Number (Re)
.040
.030
.020
.010
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
800,000
V & VI
K
C=80
r/k' = 60
IV
C=90
E
F
r/k' = 126
III
II
C=100
r/k' = 252
C=110
I
J
C=120
r/k' = 507
I
H
G
C=130
C=140
C=150
2" Brass Pipe, 10' long - Spirally Grooved - Streeter - Proc. A.S.C.E. Feb. 1935
Curve No. Depth of Groove No. per Inch Type
I .005" 46
II .005" 23
III .005" 23
IV .012" 23
V .012" 23
VI .016" 11.5
2.5, 5, & 10 Cm. Pipe - Sand Grains Glued to Inside - Nikuradse
(See Streeter's Paper) k = dia. of sand grain r = radius of pipe
8" W.I. 59' long - Artificial Tubercules - Freeman's Nashua Exp.
Curve G 92 ½"φ rubber tubercules, irregularly spaced
H 271 ½"φ ditto 8" apart
I 1038 ½"φ " 4" "
J 270 1"φ " 8" "
K 996 1"φ rubber or wood tubercules, 4" apart
4" C.I., 59' long
E ½"φ rubber tubercules, 4" apart
F ½"φ ditto 8" "
RELATION OF FRICTION FACTOR (f) TO REYNOLDS NUMBER
ARTIFICIALLY ROUGHENED PIPE
(LAB. TESTS)

FIG. 10.

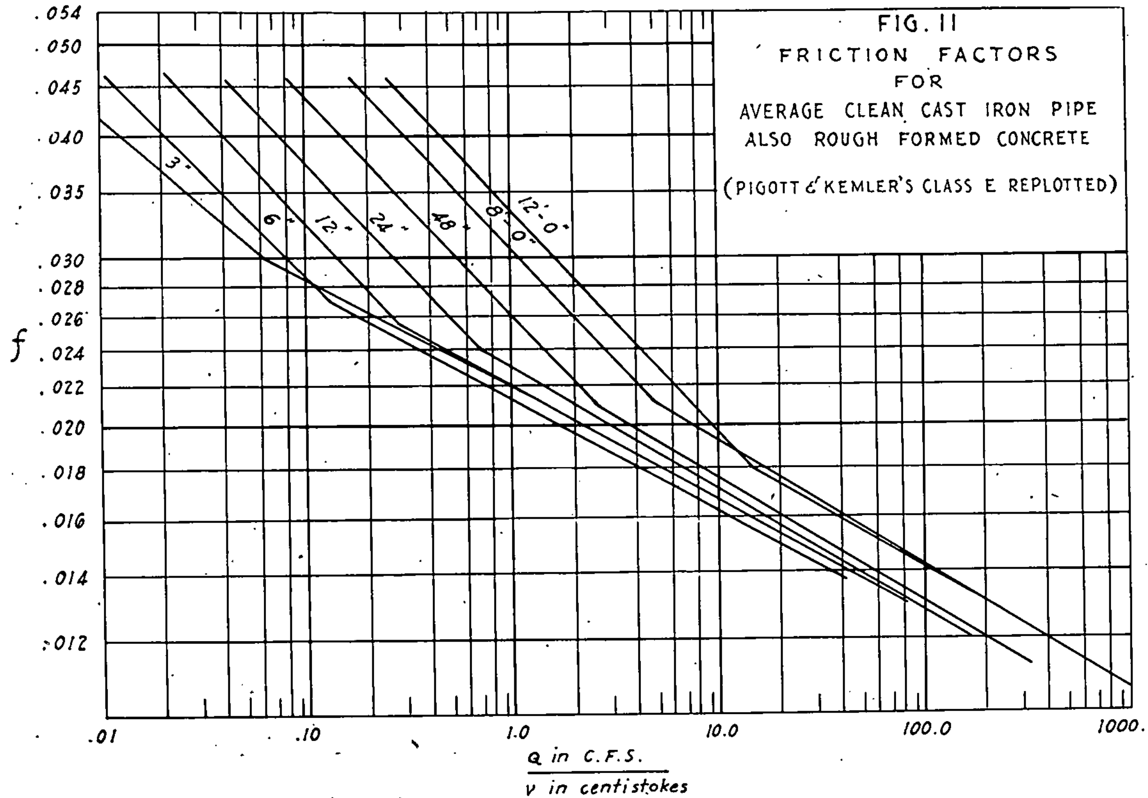


FIG. 11
FRICTION FACTORS
FOR
AVERAGE CLEAN CAST IRON PIPE
ALSO ROUGH FORMED CONCRETE
(PIGOTT & KEMLER'S CLASS E REPLOTTED)
3"
6"
12"
24"
48"
8'-0"
12'-0"
f
.054
.050
.045
.040
.035
.030
.028
.026
.024
.022
.020
.018
.016
.014
.012
.01
.10
1.0
10.0
100.0
1000.0
Q in C.F.S.
v in centistokes

FIG. 11.

In this latter relationship note that for a given pipe both n and D are constant; therefore the relation will not vary with the velocity nor with Reynold's number, and the plot will be a horizontal line. However, it should be noted that since f varies in this relationship inversely with the cube root of the pipe diameter, there will be considerable variation for pipes of different diameters. A typical example is shown below:

$n = .014$	$D =$ 6 inches	$f = .0460$
	12 inches	.0365
	24 inches	.0290

In conclusion the writer wishes to express his hope that in the future an attempt will be made to have the results of flow tests reported on the basis of a dimensionless friction factor and Reynold's number. It would seem that as the amount of such data increased in volume, a number of the uncertainties associated with the design of pipe lines would be reduced.

Bibliography

1. "Analysis of Flow in Networks of Conduits or Conductors", by Hardy Cross—University of Illinois. Bulletin No. 286, November 1936.
2. "Simplified Analysis of Flow in Water Distribution Systems", by J. J. Doland—Engineering News-Record, Vol. 117, page 475.
3. "Analyzing Flow in Pipe Networks", by Gordon M. Fair—Engineering News-Record, Vol. 120, page 342.
4. "Flow Characteristics of Pipe Lines, with Special Reference to the New Pressure Aqueduct of the Metropolitan Water District", by William F. Covil—Journal of the Boston Society of Civil Engineers, Vol. XXIX, page 22.

DISCUSSION

BY ALLEN J. BURDOIN, Member*

THIS is a very timely paper, and Mr. Cobb has done us a service by applying the Darcy formula to the solution of network problems. Dimensional analysis has shown that the Darcy formula is the fundamental basic formula for pipe flow, and tremendous progress in the study of pipe flow phenomena has been made since this fact was recognized. It is now possible by utilizing the Reynolds number to show on a single double log plot, friction factors applicable to any fluid (gas or liquid) and to any kind of pipe, provided the pipe is clean. We are still having difficulty with old and dirty pipes, although considerable progress has been made and the limits of variation of "f" have been blocked out. Probably this is because every badly tuberculated pipe is in a category by itself, and when we describe a pipe as "badly tuberculated" or "old rusty WI", it is by no means as definite a specification as "clean cast iron".

The Darcy formula is superseding the Hazen-Williams formula and all other exponential formulas of which we have had an ever growing number with exponents of V (or Q) varying from 1.75 to 2.0 depending on the size and kind of pipe and range of Reynold's numbers encountered by the experimenter, because it embraces and explains all these formulas, each of which is correct for only a limited range of conditions, and because it is the simplest formula once "f" has been determined.

The Hazen-Williams formula was a good formula for flow of water in cast iron pipe and will continue to be used by engineers for rough work for some time to come, because the tables are handy, as Mr. Cobb says, and when used for design with $C=100$ or in some cases 120, gives safe results. It is impossible, however, to ignore the Reynolds number and viscosity any longer, even when dealing with so common a fluid as water, and in the light of modern knowledge any exponential formula can be considered little better than "rule

*With Metcalf & Eddy, Consulting Engineers.

of thumb". Assuming $C=140$, a fair coefficient for the best new C.I. pipe, Hazen-Williams formula will give friction losses as much as 20% low for 32° F. water at certain Reynolds numbers and will be 20% high for 212° water at other Reynolds numbers. The Darcy formula is a universal formula which can be and is being used to design pipes carrying air, gas, steam, oil, miscellaneous chemicals and industrial wastes, as well as water, and data obtained from experiments or tests with any fluid can be correlated by means of the Reynolds number. The only question is, what value of "f" to use?

By presenting the friction factor charts, Mr. Cobb has given us a chance to correlate "f" with some of the best experimental data, and also with our past background in the use of Hazen-Williams "C". I believe, however, that the use of the double log plot for data of this kind is to be preferred.

As a profession we shall have to get used to thinking in terms of "f" and "Re". We are way behind the mechanical and chemical engineers in this, and I believe we would get along faster, if we did as most of them do and stick to viscosity in centipoises and density in pounds per cubic foot, thus forgetting those two abominations, the "slug" of mass, and that awkward and nameless English unit of viscosity. Then

$$Re = \frac{VDw}{.672\mu} \times 1000$$

in which Re = Reynolds number

V = velocity in feet per second
D = diameter in feet
w = density in pounds per cubic foot
μ = absolute viscosity in centipoises

One doesn't need an alignment chart to solve anything as simple as that.

It is possible to write the Reynold's number in a score of ways, introducing diameter in inches, quantities in c.f.s., g.p.m., m.g.d., c.f.m., pounds per hour, specific gravities, etc., and many of these are advantageous if located in a handy place in one's notebook, but there seems to be something about academic minds that objects to this procedure, possibly because they are more intent on teaching their students the four systems of units, than they are on teaching them how to figure and use the Reynold's number.

There are more data on "f", however, than most civil engineers realize. I need only mention the exhaustive study of Pigott & Kemler,* made in 1933 and covering all existing experimental data.

The diagram which they presented for values of "f" has been reprinted in numerous books including Daugherty's "Hydraulics", Kent's "Mechanical Engineer's Handbook", Mark's "Mechanical Engineers' Handbook", and "Cameron Hydraulic Data". It is unquestionably the best classification of existing data on pipe friction factors available at the present time, but it is for clean pipes only.

I have replotted Pigott & Kemler's curves for Class E pipe (average cast iron) as shown in Fig. 11. The diagram gives values of "f" as ordinates against Q/ν as abscissae for different pipe sizes.

The ordinate "f" is dimensionless, Q in c.f.s., and ν in centistokes. Since ν is 1 centistoke for 68° water, the curves may be used directly for water of this temperature, and generally for any fluid by using the proper value for ν.

Most works on hydraulics contain tables of "f" tabulated with pipe diameter as one index and velocity as the other. One of the best for clean cast iron pipe is the one given in Russell's "Hydraulics," 5th Edn., page 185. This may be more convenient than the diagrams in some cases, but it only applies to water and, strictly speaking, only to water at normal temperatures.

For old pipes perhaps the best procedure at the present time is to multiply the head loss by an age factor. This will lie between 1.5 and 2 if one wishes to obtain values approximately equal to $C=100$. An alternative method, that appears to have possibilities, would be to determine the upper limit of "f" from a curve or formula such as Schoder's formula for "extremely rough" pipes. This formula is:

$$h_f = .00069\frac{LV^2}{D^{1.25}}$$

in which h_f = head loss in feet
L = length in feet
D = diameter in feet
V = velocity in feet per second,

*"Flow of Fluids in Closed Conduits" by R. J. S. Pigott, Mechanical Engineering, Aug. 1933, and "A Study of the Data on the Flow of Fluids in Pipes," by Emory Kemler, Trans. A.S.M.E. (1933) paper No. HYD-55 Z.

which is the same as the Darcy formula, with $f = \frac{.0384}{D^{0.25}}$. It is probable, however, that the exponent of D is not as large as 0.25. If this is done it will be necessary in cases of badly tuberculated pipe, especially with the smaller sizes, to deduct something from the diameter of the clean pipe to allow for incrustation. The relative effect of ½-in. reduction in diameter is apparent from Mr. Cobb's Table II giving values of G for lined pipe. When the last word has been written on this subject, there will still be ample room for judgment on the part of the engineer.

At the present time there seems to be little excuse for using the Manning formula for cast iron pipe, since it ignores the Reynold's number and fails to fit the experimental data, even for rough pipes, unless "n" is made to vary with the diameter to make up for the fact that the exponent of the hydraulic radius, R, is too large.

OF GENERAL INTEREST

LIBRARY OF BOSTON SOCIETY OF CIVIL ENGINEERS

New Rules

(*Adopted March 22,* 1944.)

Books and periodicals may be used in the Society rooms by members and friends.

Members may borrow books for home use—with the exceptions noted below—but no one shall have more than four books at any time. Books may be kept for two weeks and may be renewed for another additional period of two weeks provided there has been no call for the books in the meantime. At the end of renewal period the books must be returned to the library.

Volumes belonging to a set—such as volumes of bound periodicals and of proceedings or transactions of societies—and such other books as the Library Committee may designate, may be taken from the rooms for a limited time only, by special arrangement with the attendant. They shall be subject to recall at any time.

A member borrowing a book shall at the time give a receipt therefor.

A fine of five cents per day per volume shall be charged for overtime, and must be paid before the delinquent can take any more books.

Reference books, indexes and current numbers of periodicals must not be taken from the rooms.

Books of unusual value are marked with a star (*), and must not be taken from the rooms, except by written permission from the Librarian, to be filled by the attendant.

Any person who violates the above rules may, upon written request from the Librarian to the Board of Government, be debarred from the privileges of the library for such time, not less than three months, as the Board of Government may determine.

BOOK REVIEWS*

Potpourri

There is little doubt that the demand for non-fiction is greater than ever before; particularly that type written not only to impart information but also written for those who do not care to struggle with their reading after the day is done. It is significant that more non-fiction is being written with a view to enjoyment in the reading. It is hoped that this trend will continue in a larger scale and not be pigeon-holed as a war measure.

* * *

Scientists have shown they can write entertainingly if they set their mind to it, and in the doing they gain a wider reading circle and extend their sphere of influence well beyond their academic circles. Roger D. Rusk's recent book *Forward With Science* (Alfred Knopf,

*By R. Newton Mayall, Landscape Architect and Engineer, 50 Beacon Street, Boston, Mass.

N. Y., 308 pp. Ill., $3.50) is such a book.

* * *

Forward With Science carefully interprets the developments in modern science, for the layman; it offers an excellent over-all picture of scientific discovery and theory. Excellent reading for all ages.

* * *

Time, as it is applied to the calendar, has come off the press in an extremely interesting and readable book *The Calendar For Everybody,* by Elisabeth Achelis, G. P. Putnam & Sons, N. Y., 140 pp. Ill. $1.50). This book is of greater importance at the moment due to the recent activity for the adoption of the Edward's Universal Calendar, in this country. Calendar revision is bound to come some day and Miss Achelis's book cannot be cast aside if one is to judge the relative merits of various new calendars proposed. As President of the World Calendar Association, Miss Achelis is well fitted to present the story of World Calendar; and she does, in a pleasant manner.

* * *

Fletcher Pratt's, *Secret And Urgent,* The Story of Codes and Ciphers (Blue Ribbon Books, Garden City, 282 pp. Ill., $1.00) is good for several evenings' diversion.

* * *

On the more thoughtful side is Harlow Shapley's, *Galaxies* (Blakiston, Philadelphia, 22 pp. Ill. $2.50), another in the series of Harvard Books on astronomy and in keeping with others already reviewed on this page and worthy of inclusion in any library.

* * *

Again on the thoughtful side is Kirtley Mather's latest, *Enough And To Spare* (Harper & Bros., N. Y., 186 pp. Ill., $2.00), which announces that man's trouble is ignorance; that we do not need to scramble to survive; that the laws of nature are not the so-called laws of the jungle; that the Golden Rule is not sentiment but law.

This eminent geologist carefully develops the theme that the earth's non-renewable resources (coal, oil, iron, etc.) and its renewable resources (water-power, etc.) are "enough and to spare," for this generation and generations to come.

* * *

BY THE WAY have you noticed that glistening and expanding group of new technical books in the Society's rooms, waiting to have the shine taken off?

PROCEEDINGS OF THE SOCIETY

APPLICATIONS FOR MEMBERSHIP

[October 20, 1944]

The By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission

GEORGE S. BRUSH, Essex Junction, Vermont. (b. March 1, 1884, Stillwater, Minn.) Graduated from Newton High School. Attended Mass. Institute of Technology. Experience, 1908-1916, with Boston Elevated Railway, in transportation, and chief clerk of subway division; 1916-1917-1918, manager, Railway Department, Cumberland Power and Light Company at Portland, Maine; seven months as General Superintendent, Springfield Street Railway, Springfield, Mass.; 1918-1924, General Superintendant, Houston Electric Company, Houston, Texas; 1924-1926, Vice-President and then President, Ballard Oil Equipment Company, Boston and New York; 1926-1929, New England Oil Company as assistant to President; 1929-1944, Shell Oil Company, Boston and New York, assistant to President, 1929-1932, asphalt department, 1932-1944, while in later job was manager New England Asphalt sales and work consisted of not only selling, but worked on designing and laying out highway and airport paving for cities, states and federal jobs. At present retired, doing consulting work on paving etc. Refers to *R. W. Coburn, L. M. Stewart, T. F. Sullivan.*

ALBERT L. COYNE, Cambridge, Mass. (b. October 3, 1891, Sturbridge, Mass.) Graduated from University of Maine (1915) in Civil Engineering. Employed by contractor on general construction work until 1917. Enlisted in U. S. A. in 1917. Transferred to Construction Quartermaster, Camp Devens, as engineer, commissioned 2nd Lt. Construction Division as assistant to Construction Quartermaster, Camp Upton, New York, in charge of engineering roads, buildings and sewage disposal plant until 1919. First Lt. in charge of maintenance of buildings 1919-1920; employed by contractor New York City as steel foreman and engineer 1920-1922; engaged in business 1922-1931; appointed teacher, 1931, Rindge Technical School, Cambridge, Mass., acting head, Mechanical Drawing Department; 1933 to present co-founder of Mechanical Drawing Association of New England. President of same 1934-1939; conducted teacher training course Harvard University, 1938-1938: conducted teacher training course M.I.T., 1939 and 1940; State University Extension courses, 1937-1940; instructor, U. S. training course, Harvard University, 1941. Instructor U. S. Navy V-12, Harvard University, 1943. Employed at present, in addition to teaching, by Jackson & Moreland Company, Engineers, Boston, Mass. Received Master's degree from Harvard in 1937. Refers to *H. P. Burden, E. H. Cameron, J. S. Crandall, R. H. Lindgren, E. J. Oakes.*

ERNEST L. SPENCER, Medfield, Mass. (b. May 17, 1913, Norwood, Mass.) Graduated from Norwood High School in 1931, B.S. Degree in Civil Engineering from Northeastern University in 1936; M.S. in Civil Engineering from Harvard University in 1943. Experience, June, 1936 - September, 1937, Everett M. Brooks, Newtonville, Mass., chief of party, land surveys; September, 1937-December, 1937, M. D. C. Parks Division, Topo. Drafting; December, 1937-January, 1938, Lewis W. Perkins, Hingham, Mass., transitman, surveys and street layout; January, 1938-March, 1939, Jackson & Moreland, Boston, Mass., Assistant Engineer, Constr. 1937 extension to L. Street Power Station, Lines, grades, inspection materials handling, etc.; March, 1938-December, 1939, Massachusetts Department of Public Works, Waterways Division, Junior Engineering Aide, survey, beach erosion soundings for dredging; December, 1939-September, 1944, Northeastern University, Instructor in Civil Engineering; September, 1944, Assistant Professor in Civil Engineering at Northeastern University. Refers to *C. O. Baird, A. E. Everett, E. A. Gramstorff, G. H. Meserve.*

WILLIAM E. STANLEY, Belmont, Mass. (b. August 14, 1891, near Hutchinson, Kansas.) B.S. degree in Civil Engineering in 1912, Kansas State College; 1913-1916, Hydraulic Engineering, C.E., 1916, Purdue University. Experience: 1912, Bridge Inspector, Kansas State Highway Commission; 1913, Land Surveyor, U. S. Land Office; 1913-1917, Instructor in surveying and hydraulics, Purdue University; Summer 1915, assistant engineer, Kansas State Highway Commission, city pavements; 1916, assistant engineer, Pearse & Greeley, Chicago, Illinois, on garbage and sewage disposal studies; 1917-1919, military service, 1st Lt. and Capt., Corps of Engineers, A.E.F., France; 1919-1922, Resident Engineer, Pearse, Greeley & Hansen, on sewer construction, Charleston, West Virginia, and dam construction, Decatur, Illinois; 1922-1924, Designing Engineer, Pearse, Greeley & Hansen, Chicago, Illinois, water works and sewerage; 1924-1936, Consulting Sanitary Engineer, junior partner, Greeley & Hansen, Chicago, Illinois, supervision construction, later in charge of project studies for water supply, sewerage, sewage treatment, stream pollution, refuse and garbage disposal, industrial wastes and stream pollution; 1936-1941, Professor of Sanitary Engineering, Cornell University, Ithaca, N. Y.; Summer 1938, charge of design, Springfield, Mass., intercepting sewers and sewage treatment; 1941-1942, Project Engineer, and Chief, Sewerage and Incineration, Construction Division, War Department on Camp Construction; 1942-1944, military service, U. S. Army Major, Corps of Engineers, Water Supply Officer, 7 months; Chief of Construction, S.O.S., 8 months in North African Campaigns. 1944 to date, Professor of Sanitary Engineering, Mass. Institute of Technology. Refers to *C. B. Breed, T. R. Camp, E. S. Chase, D. W. Taylor, J. B. Wilbur.*

Transfer from Grade of Student

RICHARD F. DUTTING, Winchester, Mass. (b. March 30, 1923, Springfield, Mass.). Entered Northeastern University September 4, 1941 and remained there until June 1943. Inducted into the U. S. Naval College Training Program July 1, 1943, and transferred to Tufts College, Medford, Mass. Received B.S. Degree in Civil Engineering from Tufts College in October, 1944. Under the cooperative plan at Northeastern University was employed by Liberty Mutual Insurance Company as Engineering Draftsman. At present am at the Naval Construction Training Camp preparing for a commission of Ensign in the U. S. Naval Reserve. Refers to *C. O. Baird, H. P. Burden, E. A. Gramstorff, G. W. Hankinson, F. N. Weaver.*

CARLE R. PALADINO, Waltham, Mass. (b. August 5, 1920, Waltham, Mass.) Graduated from Northeastern University in June, 1944. Experience, under the cooperative system, was employed by the City Engineer of Waltham from November, 1941 to January, 1942; April, 1942 to June, 1942; September, 1942 to November, 1942; February, 1943, to June, 1942; duties consisting of rodman, transitman, calculation for drainage and water systems, street construction, estimates and other jobs of that nature. At present employed by the Gruman Aircraft Engineering Corporation, serving an apprenticeship before entering the engineering department. Refers to *C. O. Baird, C. S. Ell, A. E. Everett, E. A. Gramstorff.*

Transfer from Grade of Junior

ALBERT E. ABRUZZESE, Wellesley Hills, Mass. (b. June 5, 1916, Boston, Mass.). Attended North Carolina State College of Engineering from September 1934 to June 1936; Lincoln Technical Institute 1936 to 1941. Experience, rodman, Boston City Planning Board; January, 1937 to October, 1938, draftsman and transitman, Boston Consolidated Gas Company; October, 1938 to December, 1938, transitman, George P. Carver Engineering Company, Boston; January, 1939 to April, 1939, draftsman, Metcalf & Eddy, Boston; April, to September, 1939, Field work, Metcalf & Eddy, Boston; October, 1939 to December, 1939, transitman and partyman, John Bowen Company Contractors, Boston; December, 1939 to present, engineer draftsman, George P. Carver Engineering Company, Boston, Mass. Refers to *H. Brask, A. J. Burdoin, P. S. Rice, A. L. Shaw.*

MINUTES OF MEETING

Boston Society of Civil Engineers

September 27, 1944.—A regular meeting of the Boston Society of Civil Engineers was held this evening at Richards Hall, Northeastern University and was called to order at 7:00 by Professor Harry P. Burden who has become President automatically according to the By Laws by filling the vacancy caused by the death of Samuel P. Ellsworth on August 13, 1944. One hundred sixty members and guests were present and one hundred sixty persons attended the dinner.

The President announced the death of the following members:—

Samuel M. Ellsworth who was elected a member May 21, 1930 and who died August 13, 1944. (Elected President of BSCE March 17, 1944).

Ernest F. Gallagher who was elected a member May 20, 1931, and who died June 22, 1944.

Frederic N. Fay who was elected a member March 17, 1897, and who died June 5, 1944.

Herbert C. Keith who was elected a member January 20, 1886, and who died June 2, 1944.

Nathan C. Burrill who was elected a member December 15, 1915, and who died May 26, 1944.

Albert E. Kimberly who was elected a member October 19, 1904, and who died April 21, 1944.

The President outlined briefly some of the activities and accomplishments of late President Samuel M. Ellsworth.

This meeting was the customary Annual Student Night held with representations from the Student Chapters of the American Society of Civil Engineers at Massachusetts Institute of Technology, Tufts, and of Northeastern University, which is also a Section of the BSCE. This meeting was a Joint Meeting with the Northeastern Section of the American Society of Civil Engineers and with the Highway Section of the Boston Society of Civil Engineers.

The dinner was held in Commons Hall, in the New Engineering Building of Northeastern University. The Student Engineering Society at the University as hosts arranged the details of the dinner and assisted in other ways in using the facilities of the school which had been made available by the faculty members.

The President extended a cordial welcome to the one hundred students present and expressed appreciation of the cooperation of the officers of the student organizations and of the faculty members in making this event so successful.

President Burden stated that details for the October meeting would be announced later.

The President called upon Mr. Francis H. Kingsbury, President of the Northeastern Section, ASCE to conduct any matters of business required by that Society. The President also called upon Prof. Charles O. Baird, Chairman of Highway Section BSCE, to conduct any matters of business required by that Section.

President Burden then introduced the speaker of the evening, Prof. Charles B. Breed, Professor of Civil Engineers, Mass. Institute of Technology, who gave an interesting paper on "Land and Air Transport after the War." The talk was illustrated with slides.

Adjourned at 9:30 P.M.

EVERETT N. HUTCHINS, *Secretary*

DEATHS

SAMUEL M. ELLSWORTH, August 13, 1944.

JAMES L. CRANDALL, October 18, 1944.

ADDITIONS

WILLIAM G. HORTON, 36 Jackson Road, Belmont 78, Mass.

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ADVERTISEMENTS

The advertising pages of the JOURNAL aim to acquaint readers with Professional and Contracting Services and Sources of Various Supplies and Materials. You would find it of advantage to be represented here.

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