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ICEBREAKING BY TOW ON THE MISSISSIPPI RIVER WITH MV RENEE G

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INTRODUCTION

During February 1972 a field investigation of icebreaking by a conventional towboat, the MV, (motor vessel) Renee G, was conducted on the Mississippi River between Alton, Illinois, and Fort Madison, Iowa. The operation encountered a wide variety of ice conditions and was performed with a variety of barge configurations and arrangements. Important qualitative observations were made of the nature of icebreaking and difficulties encountered. Instrumentation of the propeller shafts and use of load cells between the towboat and the barges allowed quantitative information to be obtained of the resistance encountered while icebreaking.

TOWBOAT DESCRIPTION

The towboat used in this study was operated by the Alter Co. of Davenport, Iowa. It was a twin-screw, 3200-hp, diesel-powered towboat, 141 ft long and 35 ft wide, which drew a little less than 9.0 ft when fully loaded (See Fig. 1). The

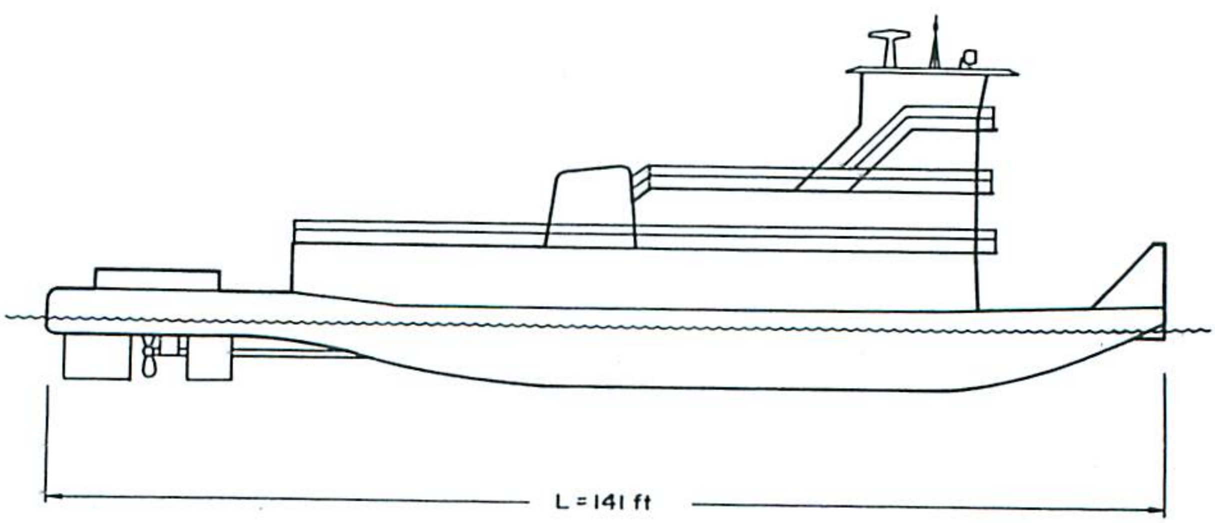

Figure 1. Elevation drawing of MV Renee G.

hull was constructed of 3/8-in. plate steel, with longitudinal stiffeners at about 6-ft centers and transverse stiffeners at about 18-in. centers.

BARGE CONFIGURATIONS AND ARRANGEMENTS

The barges used in the investigation were conventional bulk commodity barges of several types. Barges with raked ends were 35 ft wide by 195 ft long while barges without raked ends were so-called "extra long," with dimensions 35 ft by 200 ft. Nominal load capacity of each barge was 1600 tons net and draft varies from almost 9 ft when loaded to about 1 ft when empty. The various barge arrangements used during the investigation are depicted in Figure 2. Included

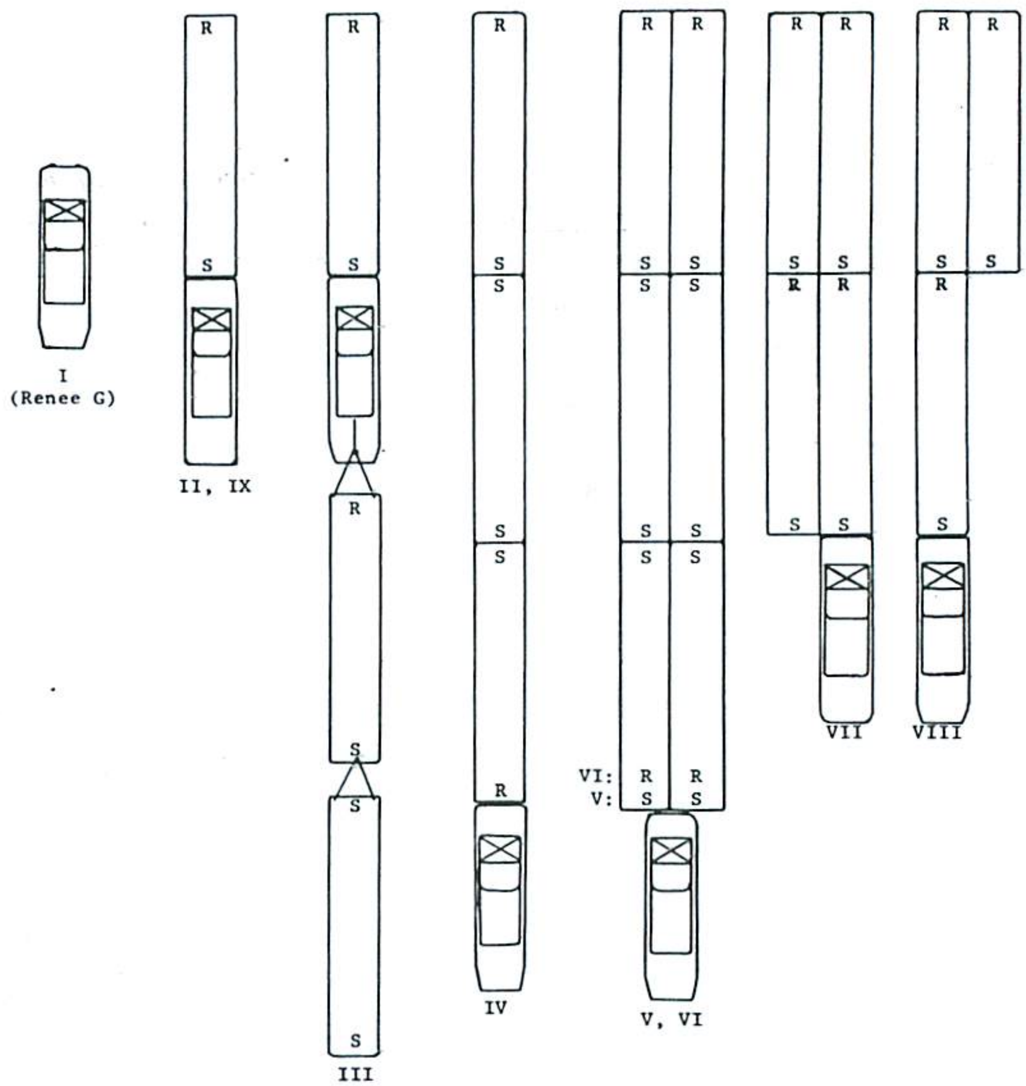

Figure 2. Barge arrangements.

in Figure 2 is the Renee G alone, as it was occasionally used "bare boat." During normal operation (barges ahead of towboat as shown in Figure 3) the barges and towboat were rigged together with 7/8-in. diameter wire cables by means of

Figure 3. Pushing barges ahead.

face lines (either two or four part) on each side of the bow of the towboat. Each face line ended in a power winch that was used to tighten the cables. During the icebreaking tests with load cells installed between the towboat and the barges two additional criss-cross wires were used to minimize lateral movement of the barges.

ICEBREAKING BEHAVIOR

The behavior of the ice, and consequently the action of the tow and/or barges, varied considerably, depending upon the ice conditions encountered. Conversely, the various arrangements of barges, the speed of the tow, and operational variations in maneuvering resulted in different icebreaking behaviors.

The behavior of the tow when moving through open water with occasional loose ice floes or fragments was essentially the same as in open water. When the fragments were small, say less than 4 ft in diameter, they moved with the water and there was no evidence of an increase in resistance to movement exerted on the tow. When a larger flow was struck by the bow, it was initially accelerated forward. The upstream edge sometimes submerged and the floe might break by bending. In general there appeared to be little interference with movement of the tow or increased resistance. When an empty square-ended barge was moved a short distance through large, loose floes, a very strong "lurching" of the tow was felt, and there was a definite increase in resistance. The "lurching" coincided with contact with large floes which broke up in passage. The contrast between the observed motion with the square end of the barge forward and the steady motion observed when pushing a single barge with rakes bow is noteworthy and points out the advantage of a raked bow.

On a number of occasions the tow moved through an ice cover consisting of large floes in contact with each other but not in a jammed state. The significant difference in this case when compared with the case of a jammed cover was in the behavior of the floes at the bow and along the sides of the barges. In this case floes were either accelerated forward initially (See Fig. 4), or were bent, broken and passed under the bow. Both modes of behavior occurred, depending upon the speed of the tow and the degree of packing. When the floes were closely packed the tendency was to bend under the tow, crack laterally in front, and pass under the bow without overturning. When the floes were loosely packed, individual floes sometimes accelerated forward of the bow, their leading edges submerged and they either overturned and were swept under the bow or broke up

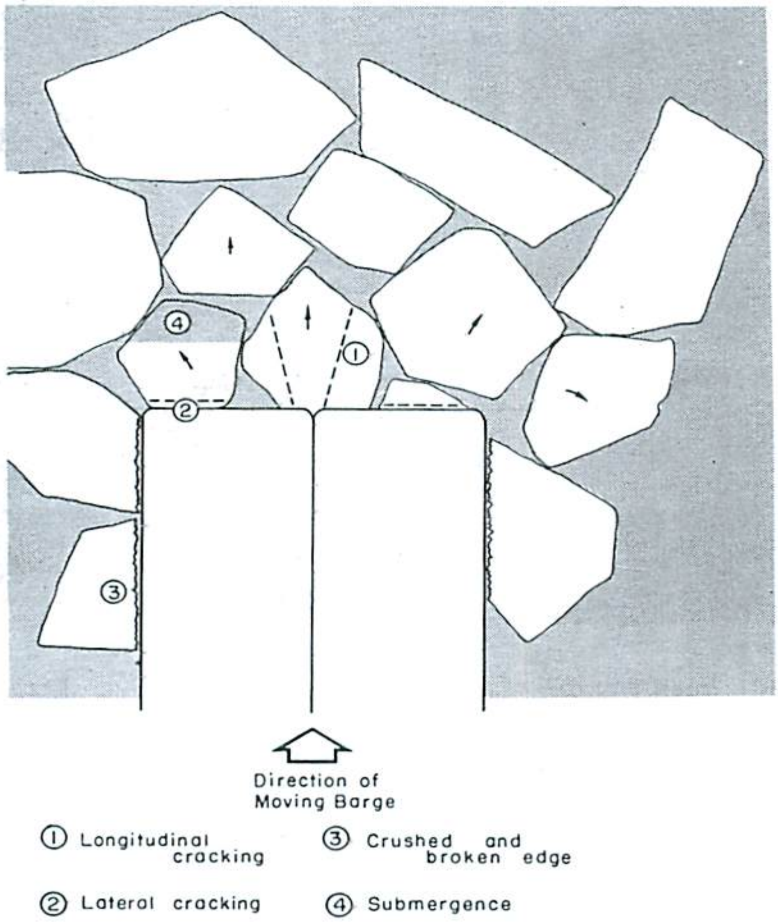

Figure 4. Modes of behavior of large floes.

and passed under the bow without overturning. Finally, in some cases, particularly when the floes were very large (greater than about 50 ft in diameter), they split longitudinally ahead of the bow before undergoing the behavior described above. In some cases these longitudinal cracks extended as much as 100 ft ahead of the bow. They often originated at locations other than in the vicinity of the tow knees.

An ice cover consisting of loose brash offered little difficulty to passage of the tow. In many respects the brash acted as if it were fluid and many of the same characteristics observed while moving through open water conditions were noted: a breaking bow wave, a depression of the water surface just aft of the leading corners of the barge, a tendency for the brash to collect in the wake behind a blunt-ended barge, in short, water movement virtually identical to that of water with no ice cover. During a turn there was a tendency for the brash to compress on the outboard side and to spread on the inboard side. There was, of course, some reduction in speed compared to open water conditions but this was minor compared to the reduction effected by a heavy brash cover.

Heavy brash conditions varied from closely packed but not very thick ice to an extreme case in which the brash was several feet thick and seriously hampered movement of the tow. The ice behavior during passage of the tow varied somewhat although certain general features may be described.

Just ahead of the bow the brash tended to pile up, often above the front deck of the lead barge, resulting in some cases in spillage onto the bow (See Fig. 5). More often, however, the pile did not exceed the bow deck height but was

Figure 5. Brash ice piled above bow of barges.

somewhat higher than the usual breaking bow wave that forms in open water. A common aspect of the behavior in heavy brash was the creation of an ice prow of piled brash ahead of the tow. This generally had a triangular shape with the apex forward but not necessarily centered. The oncoming brash sheared along the edges of the ice prow more or less at an angle of 45° with the bow front as would be expected if internal friction were neglected. The oncoming brash, besides shearing off to the sides, also submerged and passed under the bow. When the tow was moving through a narrow track filled with brash, ice sometimes accumulated ahead of the barges for distances up to 200 ft. The brash thus accumulated was constrained from moving laterally by the intact ice cover bordering the previously broken track. As the ice accumulated, progress of the tow was progressively impeded. A number of times a backing and ramming procedure was attempted with the ostensible purpose of freeing the accumulated ice. These efforts did not seem to relieve the problem until an area of weakened border ice or open water was encountered. Further, there appeared to be some critical speed above which this progressive accumulation did not occur, and of course, once accumulated, the ice mass prevented this speed from being attained.

The brash, once past the bow area, appeared to be cast to the sides of the tow. As the stern of the tow passed, some of this ice was drawn back into the track area by the propeller suction and by entrainment in the wake. Only small amount of ice appeared to pass longitudinally under the tow along its full length.

The most difficult ice conditions encountered during the investigation occurred when an extremely heavy accumulation of brash and floes across the entire channel area caused complete stoppage of the tow (with six barges). Repeated backing and ramming eventually resulted in passage through the jammed area although at one point only 200-400 ft of progress was attained in each backing and ramming operation. Undoubtedly, part of the resistance to passage was caused by the accumulation of ice on the undersides of the barges. Once in place, this ice was not entrained into the passing flow until the tow increased its speed. This bottom accumulation was evidenced by the ejection of ice fragments, more or less uniformly along the length of the tow, for about a mile after entering the open water beyond the jammed area. The ejected ice fragments formed a loose band about 20 ft wide on each side of the barges and provided an estimate of the lateral extent of the disposition of fragmented ice when moving through an ice cover.

The track behind the tow in a heavy brash cover tended to be irregularly edged and to "close," depending in part upon the quantity of brash. The "increased resistance" noted in deep, heavy brash may also be caused by a drop in effective thrust. The propellers are simply circulating water in an enclosed pool.

The behavior of the tow when passing through a frozen brash cover ranged from the behavior when encountering a loose brash cover to the behavior in an intact ice cover, the degree of similarity depending upon the extent of refreezing. In one reach a completely refrozen brash cover was encountered. It behaved identically to an unbroken ice cover even though there was marked surface evidence of the previous track. At other times the extent of refreezing of the brash was so little that no noticeable difference was observed between this condition and a loose brash cover.

Just as open water with occasional brash represents one extreme of ice conditions, an intact, unbroken ice cover represents another extreme. Psychologically an unbroken ice cover appears to be a formidable barrier to passage of a tow in winter. In many respects, however, its very uniformity offers advantages to navigation.

The simplest case will be considered first: a tow consisting of one or more barges in line pushed ahead of the towboat and moving in a straight line.

As the barge moved forward the ice bent downward and passed beneath the bow. While the barge was moving through the ice, lateral fracturing could clearly be seen just ahead of the barges. Little cracking outward from the sides of the barges was observed and the barges cut a "clean" path through the ice, only slightly wider (a few inches at most) than the tow width. The cleanly cut edges and relative lack of disturbance of the ice outward from the sides of the barges are clearly shown in Figure 6. There was no observed tendency for the barges to "ride up" on the ice sheet in front although the Captain said this sometimes occurs with empty barges in "heavy" ice, particularly consolidated thick brash.

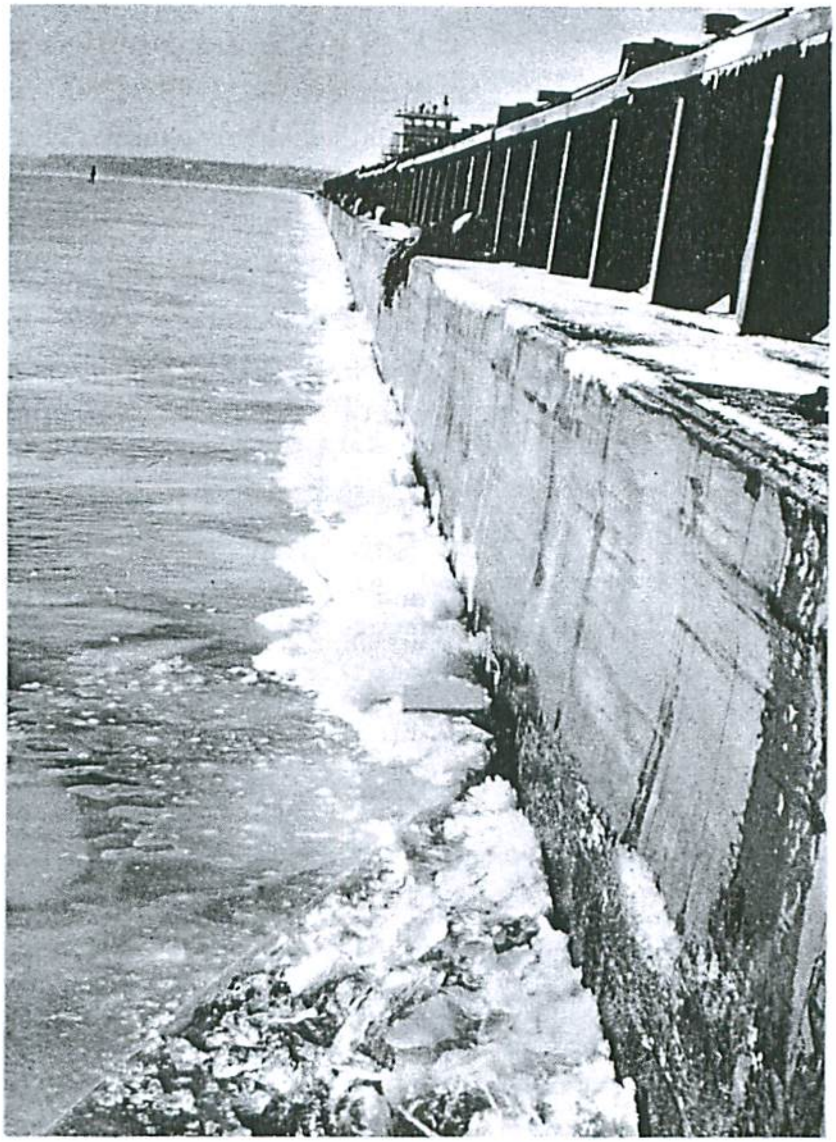

Figure 6. View of ice along sides of barges during passage through an unbroken ice cover.

Also of importance in assessing the difficulty of moving through an intact ice cover is the longitudinal force resulting from friction between the barge sides and the adjacent ice. After the tow was stopped in an intact ice cover for two hours it was unable to resume passage until after the ice was broken along one side of the barges. The additional forces preventing movement were mo probably due to two causes: freezing and adhesion of the adjacent ice to the si of the barges, and pressure of the ice against the sides of the barges.

Perhaps the greatest difficulty during passage through an unbroken ice cove occurred during turns. If the turn was very gradual it could sometimes be negotiated without stopping and backing although the speed was greatly reduced. If the turn was not gradual it was necessary to stop the tow back several hundre feet, and then cut a new track in the direction of the turn. Generally, several backing and ramming operations were required to negotiate a turn, depending on t angle of the turn and the radius of curvature. An indication of the number of such maneuvers required to negotiate a given turn can be determined from the observation tl each maneuver generally resulted in one tow width gained over the length of the tow in eac maneuver (see Fig. 7). Thus, for a 70-ft-wide tow 595 ft long the angle of turn accomplishe in each maneuver was of the order of $\tan^{-1} 70/595 = 7°$. The shorter the tow the greater angle of turn accomplished in each maneuver.

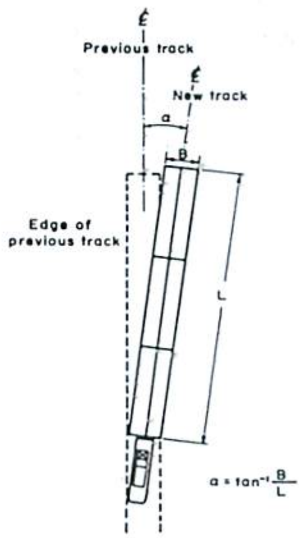

Figure 7. Angle of turn negotiated in each backing sequence.

It is a relatively common procedure when operating in difficult ice conditions to "mule-train," i.e. one barge is pushed ahead and the remainder towed behind, one after another, connected by wire rope lines. Durin this investigation mule-training was conducte during the first passage upstream for about 4 miles. The only apparent advantage of this m of operation lies in the enhanced ability to negotiate turns in severe ice conditions.

On the other hand there is an inherent instability of the trailing barges and "jackknifing" occurs in open water or loose brash. During movement through heavy ice the forces exerted by the ice on the outside of the barge are suffici to prevent this jackknifing. The track left behind when the tow was moving through an unbroken ice cover tended to be wider than the barges and to be irregularly edged. These effects are due both to the action of the propeller backwash on the trailing barge bow and to the jackknifing.

EFFECTS OF REPEATED PASSAGE

It is natural during an investigation of this type to concentrate attention on the behavior of the tow in an intact, unbroken ice cover. Should year-round navigation be conducted, however, such conditions will be the exception rather than the rule, except locally during docking operations or when passing another tow. The more usual condition will be that of passage through a track previously broken in the ice cover. During this investigation a number of observations were made of the effects of repeated passage.

The condition of a newly broken track depended in part upon the way in which it was created. The track was about the same width as a barge when the barges were pushed ahead, although there was a tendency for the track formed behind a single-barge-width arrangement to be slightly wider and to have somewhat more irregular edges. The mule-training arrangment definitely resulted in a track wider than a single barge and with greater edge irregularities. It was clear that some of the ice broken remained in the track and some was deposited under the adjacent edge of the intact ice cover. In the absence of aerial photographs taken just after passage of the tow an indirect means was used to estimate the relative amounts of each.

It was observed a number of times that the broken ice in the track tended to consolidate in one layer in places with open water patches between. The areas of these open patches relative to the total surface area of the track were determined by recording the times of passage through the track with open water and with brash cover on several occasions. The initial passage through an unbroken ice cover resulted in a track with considerable open water areas. However, after several passages the track became nearly entirely covered with brash. Perhaps the most obvious effect of repeated passage was the breaking of additional ice at the sides of the track by the bow wave of the barges. In this case little additional ice was cast laterally under the adjacent edge of the intact ice cover, and the major effect on the track of the repeated passage was a widening of the track area. Later passages through the center of a widened track showed a reduced tendency for icebreaking by the bow wave unless the tow was running close to the intact border of the track.

It was noted above that a portion of the broken ice was disposed of laterally in passage, particularly during the initial passage. The broken ice remaining in the track tended to consolidate, resulting in open patches of water in the track alternating with brash patches. This redistribution was due to the river currents and was resisted by the internal friction of the fragmented ice cover which in turn transmitted the forces to the edges of the adjacent unbroken ice. There was a definite tendency for the brash to accumulate at turns in the track with the heaviest accumulations at the sharper turns. When the track crossed the river the ice tended to accumulate against the downstream edge.

At a number of locations movement of the entire ice cover effectively obliterated a previous track: This condition is probably also associated with mild temperatures and imminent breakup since it was not observed where the ice cover exhibited no signs of deterioration. Neither were there observed indications that passage precipitated breakup of the ice cover before natural breakup. Other experience, in fact, suggests that passage through an ice cover may have beneficial effects toward reducing the potential for ice jams.

ICE RESISTANCE COMPONENTS

The total resistance to passage of a tow (towboat and barges) through an ice cover is the sum of the component resistances effected by the water and by the ice. The resistance of a vessel in open water is composed of the frictional resistance, R_F, the form drag resistance in the absence of waves, R_D, and the resistance due to wave making, R_W. These plus the resistance offered by the ice, R_I, comprise the total resistance, R_T:

$$R_T = R_F + R_D + R_W + R_I \quad . \tag{1}$$

It is important to note that the presence of an ice cover modified all three of the open-water components, R_F, R_D and R_W. Formal separation of the total resistance into equivalent open-water components plus a residual ice resistance, however, offers a means of including the effects of ice on R_F, R_D and R_W into R_I. In this section this is the approach taken, i.e. the open-water resistances are estimated using conventional methods and the ice resistance is then determined as a residual from the measured values of total resistance.

The frictional resistance was calculated using

$$R_F = C_F S \rho \frac{V^2}{2} \tag{2}$$

where S is the wetted surface area of the tow (length L x perimeter p), ρ is the mass density of the water, and V is the velocity of the tow relative to the water. The friction coefficient C_F was calculated using the 1957 ITTC formula (1) in the form

$$C_F = \frac{0.075}{(\log_{10} Re_L - 2)} \quad \text{where } Re_L = \frac{VL\rho}{\mu} \tag{3}$$

and μ is the viscosity. An additional correction, $C_A = 0.0004$, was added to C_F to account for effects such as hull roughness, fouling, and other effects (1). The form drag resistance is the resistance resulting from unbalanced pressure forces on the hull in the absence of waves and was calculated in the usual form:

$$R_D = C_D A_D \rho \frac{V^2}{2} \tag{4}$$

where C_D is the drag coefficient, taken as 0.07 (see Ref. 2), and A_D is a representative cross-sectional area. The wave resistance is most commonly determined from an expression of the form

$$R_W = C_W A_D \rho \frac{V^2}{2} \qquad (5)$$

where C_W is an empirical function of the Froude number ($Fr = V/\sqrt{gL}$) based on total length. Generally C_W is determined from model tests. Since model tests are not available for the tow it is only possible to estimate the wave resistance by crude means. On the other hand, the wave resistance at the low Froude numbers ($Fr<0.094$) involved in this investigation is a very small part of the total resistance (3) and was considered negligible.

In calculating the equivalent open water resistance the increased resistance due to shallow water effects was examined within the context of the methods proposed by Schlichting or Landweber (see Ref. 1, p. 320). In Figure 8 the

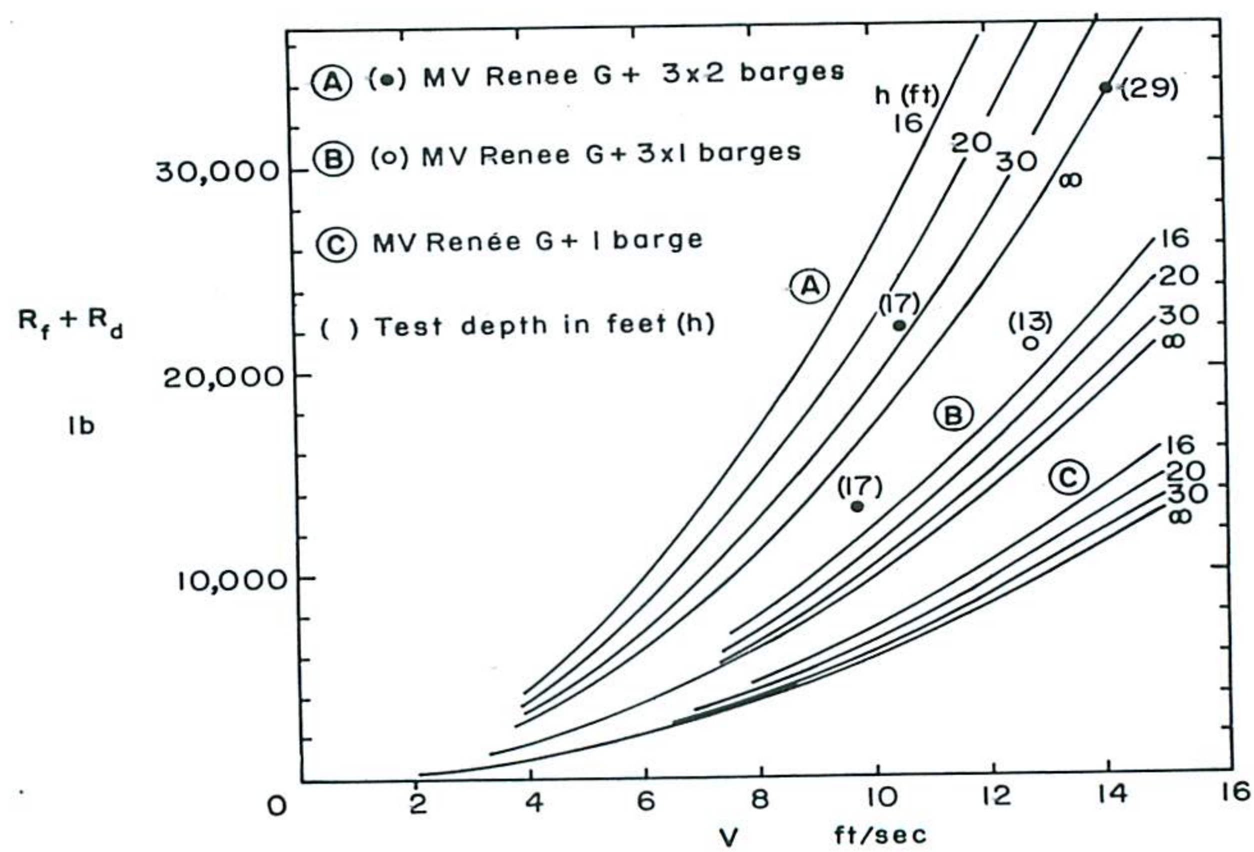

Figure 8. Calculated and observed open-water resistance of tow arrangements.

results of the calculations of open water resistance are presented for different barge arrangements and various water depths. A limited amount of data in open water were obtained during the investigation and are presented in Figure 8 also. While the agreement is not perfect it is sufficiently good that the calculated open water resistance may be used with confidence to determine the residual ice resistance at lower speeds, particularly since at these lower speeds the open water resistance is a small part of the total resistance. The total of the residual ice resistance may now be determined by subtracting the open water resistance from the observed net resistance, i.e. using equation (1),

$$R_I = R_T - R_F - R_D - R_W \tag{6}$$

INSTRUMENTATION

One of the objectives of the investigation was to determine the thrust required to move the towboat through an ice cover at various speeds, ice thicknesses and conditions, and with different barge arrangements. There are various means of determining thrust; in this study two means were used. The first consisted of measuring shaft torque and angular velocity (rpm), from which, using the propeller characteristic curves, the thrust may be estimated. The second consisted of installing load transducers between the towboat and the first barge pushed immediately ahead of the towboat. Neither system directly yields the total resistance of the tow, the first requiring knowledge of the thrust deduction coefficient and the wake fraction and the second requiring an estimate of the hydrodynamic interaction between the towboat and the barges.

The torque measurement system consisted of a four-arm strain gauge bridge, an FM transmitter-receiver, and an oscillograph to provide a visual display as well as a strip chart record of the data. Details and discussion of the procedures used to interpret the torsion strains so as to determine the effective thrust are contained in Reference 4.

A number of other variables are involved in determining resistance to a towboat operating in ice on the Upper Mississippi River. In solid ice, the bow wave is inhibited and thus the wavemaking resistance is altered. The relatively shallow river environment also increases the resistance above that which would be experienced in deep water. We have made no correction for this factor in the report. Thus, the resistance values given are subject to additional interpretation. However, for comparison of open water, brash ice, and solid ice cover resistance, they are quite adequate.

Marine engineers have always used propeller thrust as one of the basic means to measure full-scale ship resistance. However, with a towboat pushing barges a more direct alternative is possible. Accordingly two 100,000-lb load cells were installed between the towboat and the tow. Although the tow traveled a straight path and there was no rudder movement during the tests, the cells showed a cyclic and opposite variation in load, presumably due to the instability of pushing a long, thin tow. The "preload" imposed by the facing and scissors wires was simply subtracted from the total thrust. At some point during the investigation the load cells experienced internal damage. Since these data are somewhat higher than the shaft-derived figures and since the damage to the cells was quite extensive, the resulting thrust values are of questionable validity and are not presented.

Forces associated with average accelerations determined from sequential velocity measurements seldom exceeded 4000 lb and then only for short durations. No corrections for accelerations have been made.

Water velocities were measured at selected sites and found to be about 0.75 ft/sec. These velocities have been neglected and all tow velocity measurements are relative to either the open water surface or ice surface. Two reference sighting positions 100 ft apart were established on the Renee G. A wood block was tossed on the ice or in undisturbed water ahead of these two positions and the time noted on the oscillograph when each position passed the block. Consideration of possible errors in this procedure suggests that the velocities are accurate to within about $\pm$ 4%.

ICE RESISTANCE RESULTS

It is of interest to examine the thrust data further, particularly since they represent a wide variety of ice conditions and since some surprising trends in the ice resistance-velocity relationship were found. The data in this section are presented within the context of equation (6), i.e. a calculated open water resistance is subtracted from the total observed resistance to obtain the resistance attributed to the presence of the ice. This arbitrary separation of the resistance due to ice from the equivalent open-water resistance is not strictly valid. Nevertheless it is a practical means of evaluating the ice resistance, both from the standpoint of interpretation of the results as well as use in prediction of ice resistances. It is convenient to separate two obviously different ice conditions: an unbroken ice cover and an ice cover composed of brash fragments.

As pointed out earlier, a fragmented ice cover (brash) is likely to be the most commonly encountered condition. In this investigation a number of tests were conducted while moving through a brash cover. Figure 9 presents the results of these tests (R_I vs Velocity). The ice resistance shows an unmistakable decrease with increasing tow velocity. Whether this is, in fact, a real decrease or an apparent decrease similar in nature to a push-speed curve which results from a constant horsepower is unclear at this time. The data do suggest that, at least at lower velocities, the resistance offered by a brash cover is

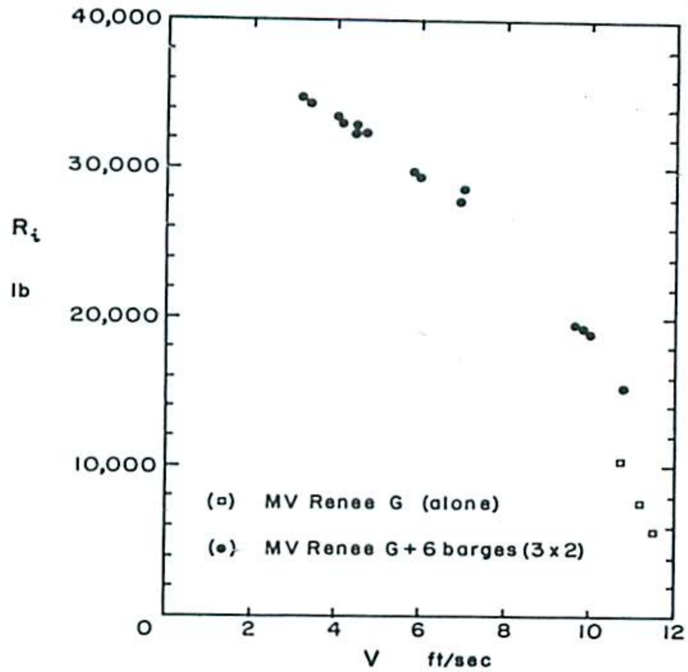

Figure 9. Ice resistance in brash cover.

substantial. One possible explanation for the trend observed is that with increasing speed, less ice is carried along by the barges. As the velocity increases, the water resistance increases approximately as the square of the velocity, with the decrease in ice resistance being "traded" for the increase in primarily turbulent boundary layer friction resistance which represents a significant part of the total resistance of the tow. When the brash ice is constrained from moving, of course, the accumulation of brash ahead of the barge may cause stoppage of the tow.

Again, using the concept of a residual resistance representing the difference between the observed resistance and the equivalent calculated open water resistance, the ice resistance has been calculated for an intact, unbroken ice cover and the corresponding values plotted in Figure 10. Again, there is a definite trend of decreasing ice resistance with increasing velocity. A detailed comparison of Figures 9 and 10 shows that, for the six-barge arrangement, there is little difference between the lines which might be faired through the data points; this suggests that the resistance due to ice breaking, per se, is but a small component of the total ice resistance. Surprisingly, there appears to be little difference in the speed-ice resistance curve between the results for three barges and for six barges although it is significant that the tow was able to move about twice as fast with three barges. The resistance was considerably lower with one barge than with three or six barges; it is noted, however, that these tests were run with only one engine in operation. As with the results of

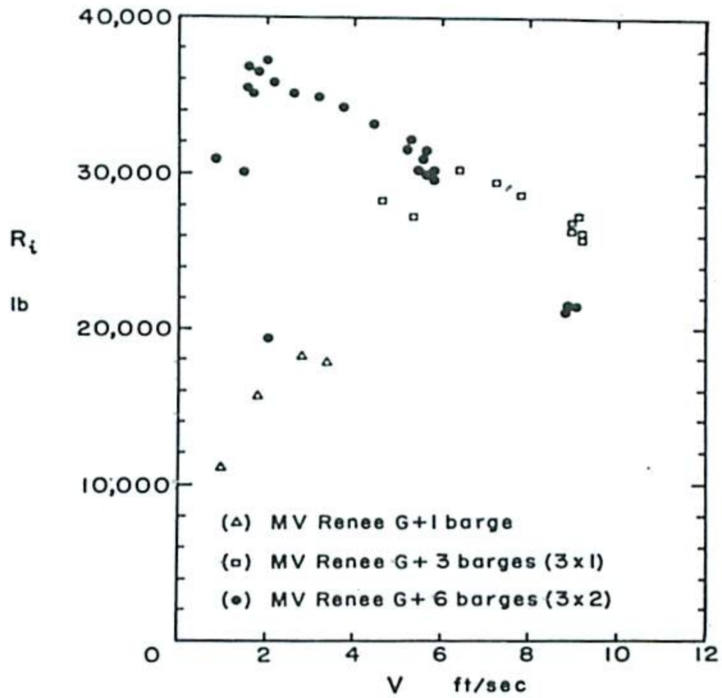

Figure 10. Ice resistance in unbroken ice cover.

the brash ice tests, it is difficult to determine whether the data represent a true decrease in resistance with increasing speed or whether they merely represent a push-speed curve at constant horsepower with ice resistance and water resistance "trading off" while maintaining the same total.

NAVIGATION PROCEDURES PECULIAR TO ICEBREAKING

A number of procedures were observed which are considered peculiar to navigation and tow operations in ice conditions. These include docking operations, locking operations, passing of other tows, and the effect of ice on navigation markers. Although some of the observations may have been unique to the particular towboat and crew of the investigation, most, if not all, are expected to be common to most tows.

In most respects lockages were accomplished in a manner identical to non-ice periods. Certain difficulties were observed and it is expected that they would be more serious during weather conditions more severe than those encountered in this investigation. A number of the locks had an ice layer accumulated on one or both walls. In all cases observed the icing was relatively minor and posed no serious difficulty. On those locks which had floating mooring buttons recessed into the walls, the mooring points were not used as they were removed from operation during the winter season. On a number of occasions during lockage there were delays resulting from ice accumulation in the upper miter gate recesses when opening the gates. The usual procedure to alleviate the problem was to hand-pole the ice fragments out of the way. On at least two occasions the lock personnel directed the Captain to proceed out of the lock when only one gate was fully recessed. Besides poling of the ice there was observed a practice of "fanning" a gate in an effort to aid in the removal of ice in the forebay between the gate and lock wall. From aboard the tow it was impossible to determine the efficiency of this fanning procedure. Finally, at lock 26 a tender, the Norbroco, appeared to be in continual use in maintaining the forebay areas free of ice. At locks with less traffic congestion than lock 26 it is doubtful that use of a tender on a continual basis can be justified economically. It is suggested that a permanently installed velocity system may prove to be more economical. In spite of the difficulties described above, the longest delay to the tow in lockage which is attributed to ice interfering with gate operation was about 15 minutes.

A number of difficulties were experienced in docking operations in ice. These included accessibility to dock areas, difficulties encountered when rigging barges and difficulties in maneuvering in the dock areas. Access to dock areas was gained either by breaking a track directly from the channel to the dock area without disengaging barges, or by the towboat disengaging and breaking a path "bare boat" while the barges were left unattended in the ice. In general there were no unusual difficulties resulting from either procedure except, of course, the added time involved. It should also be noted that the MV Renee G functioned quite adequately as an icebreaker when running "bare boat;" whether it would be as adequate in more severe ice conditions can only be conjectured at this time. On the other hand, a boat able to break a new track in a channel area certainly is able to break a path to a docking facility. Upon arrival at a dock it was necessary to break the ice where the barges were to be moored. At times this was difficult because of limited ability to maneuver imposed by the dock structures and by shallow water. Both direct frontal breaking as well as the backwash of the towboat were used to break and remove ice in the dock areas. It was also necessary to break ice over a sufficient area to allow maneuvering when spotting individual barges or when "making tow." The area required for maneuvering was roughly of a width out from the dock as long as the tow and of a length at least this long, or as long as the dock area.

When making tow and before departing a dock area considerable difficulty was experienced in rigging the barges together because of ice lodging between the barges. At one time an hour's delay was attributed to this difficulty. A more serious potential difficulty associated with wintertime navigation and docking is the problem of positioning barges for unloading (or loading) when multiple barges are docked and the towboat is not available to assist. Repositioning of barges is normally accomplished by a cable mooring system which probably would not be adequate in severe ice conditions.

One of the difficulties experienced during the investigation was due to the effects of ice on the channel marking buoys. At times buoys were simply not present where they were expected. At other times, and this is considered more serious than a "missing" buoy, they were out of position and therefore unreliable.

Finally, a number of times early in the investigation the Captain of the Renee G was of the opinion that the previously broken track passed either out of the channel or dangerously close to the sides of the channel. In such cases a new track was broken in a line more acceptable to him. There is no question but that experience on the river was an aid in navigating through ice and detailed knowledge of the river invaluable.

ACKNOWLEDGEMENT

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