5 Production Experiments and Analysis

Experiments evaluated the return velocity and drawdown for conditions and meter positions not addressed in the prototype experiments, after adjusting the physical model to reproduce the prototype. The verification experiments were conducted with the same lateral and vertical positions of the velocity and wave gauges in the model and prototype experiments. The vertical position of the velocity gauges in the production experiments was an issue that had to be resolved. Analysis of vertical velocity profile data (presented subsequently) shows that if the meter is too close to the bed, the maximum change resulting from tow passage may not be captured because the friction on the channel bottom retards the near-bottom velocities. The physical forces study also compared physical model results to a depth-averaged numerical model, HIVEL-2D (Stockstill, Martin, and Berger 1995). With the exception of the vertical velocity profile and the near dike experiments, all velocities in the production runs were measured at 60 percent of the local depth below the water surface. This position is standard for riverine surveys and ensured that the maximum change produced by the tow will be measured and could be directly compared to HIVEL-2D. The following paragraphs detail each experimental series.

Experimental Series 1—Pool Elevation 546.0

Experimental series 1 (pool 546.0), 5 (pool 551.5), and 7(pool 572.7) were used to evaluate the effects of a range of blockage ratios (channel area/vessel area) on the far-field effects of navigation. Twenty-four experiments (three replicates for each experiment) were conducted at a pool elevation of 546.0, with a discharge of 690 cms, using three-wide by five-long barges, and various tow speeds, directions, lateral positions, and drafts. The cross section is shown in Figure 26 and experimental conditions are summarized in Table 15. All experiments in this series were conducted with a 45-deg rake angle. Ambient velocity, maximum impact velocity, maximum return velocity, and drawdown below normal water level for each experiment are shown in Tables 16 to 39. To obtain a representative data set for the vector plots shown in Figures 27 to 50, the three replicate experiments were averaged and one was selected as the most representative of the mean of the three experiments. The vector plots are not based on one tow position with many different velocity meter positions as might be inferred from the vector plots. The vector plots were based on a single velocity meter position (Sta 63) and many different boat positions. Evaluating the vector plots is straightforward when the cross section is constant as in the case of the Kampsville study (Maynord and Martin 1997) where no dikes were present. When the cross section is variable, such as in the presence of the dikes at Clark's Ferry, the vector plots must be viewed with caution because the tow is a different distance from the dikes at each point in time. Because the vector plots can only provide a finite number of vectors, the maximum value was not always indicated but is provided in the tables. Table 40 summarizes the position of the velocity probes used in each experiment.

Experimental Series 2—Tow Length Experiments

Sixteen experiments (three replicates each) were conducted to determine the influence of the length of the barges on the navigation-induced forces. A pool elevation of 546.0 and a discharge of 690 cms was used with loaded barges, upbound and downbound, one sailing line, and variable boat speeds. Experimental conditions are summarized in Table 41. Ambient velocity, maximum impact velocity, maximum return velocity, and drawdown below normal water level for each experiment are shown in Tables 42 to 57. Vector plots for each representative experiment selected based on the mean of the three replicates are shown in Figures 51 to 66. Because the vector plots can only provide a finite number of vectors, the maximum value was not always indicated but is provided in the tables. Maximum return velocity for all four vessel speeds are plotted in Figures 67 and 68. Table 58 summarizes the position of the velocity probes used in each experiment. Plots of maximum drawdown versus vessel length for two speeds and left and right bank are shown in Figures 69 and 70. Both return velocity and drawdown in Figures 67 to 70 are normalized using the computed Schijf average return velocity or drawdown using the vessel speed relative to the water and the effective draft. The plots of return velocity show that the one- and two-barge-long tows tend to have high return velocity near the vessel and low return velocity away from the vessel compared to the longer vessels. Return velocity for the three-barge or longer tows are similar in magnitude. Drawdown, which was measured near the bank, was similar in magnitude for the four- and five-barge-long tows. Using vessel length to channel width as the pertinent ratio, results suggest that the return velocity and drawdown become constant for the four-barge-long vessels, which is $L/B = 238/615 = 0.39$. Additional work is being conducted with the numerical model HIVEL (Stockstill, Martin, and Berger 1975) to evaluate vessel length effects.

Experimental Series 3—Rake Experiments

Four experiments (three replicates each) were conducted to determine the influence of the rake configuration on the navigation-induced forces. The rake configuration refers to the shape of the bow of the lead barges. All experiments conducted herein were conducted with boxed ends at all connections between barges. Previous experiments by Latorre and Ashcroft (1981) have shown a significant increase in the resistance of barges with increasing rake angle for a vessel Froude number (based on vessel length) of 0.1. At low vessel Froude numbers that are typical of UMRS tows (about 0.06), results from Latorre and Ashcroft show a small effect of tow configuration on barge resistance, but it is not known if this low Froude number effect also applies to rake angle. All previous 546.0 pool experiments were conducted with a 45-deg rake angle. Data were collected and evaluated for experiments run at variable speeds with a bow rake angle of 26 deg. A tow configuration of three wide by five long was used in these experiments. The 26-deg rake was created as a plexiglass extension to be added to the tow with the 45-deg rake. This increased the length of the tow by 7 m (28 cm in model). The experiments were conducted with a flow of 690 cms and a water surface elevation of 546.0. All experimental conditions were identical to the previous pool 546.0 experiments except for the rake angle. Experimental conditions are summarized in Table 59. Impact, ambient, and maximum return velocity and drawdown below normal water level for each experiment are shown in Tables 60 to 63. Vector plots for each representative experiment are shown in Figures 71 to 74. Because the vector plots can only provide a finite number of vectors, the maximum value was not always indicated but is provided in the tables. Plots of return velocity for the two rake angles and four vessel speeds are shown in Figures 75 and 76. The drawdown comparison for the 45-deg versus the 26-deg rake angle was inconclusive because of the scatter in the data. The difference between the return velocity caused by the 45-deg rake and the 26-deg rake is negligible. All experiments hereafter were done with a 26-deg rake.

Experimental Series 4—Vertical Velocity Distribution Experiments

Six experiments (three replicates each) were conducted to determine the vertical distribution of velocity changes induced by the tow. Experiments were conducted at a pool elevation of 546.0, with a discharge of 690 cms, three-wide by five-long barges, barges on thalweg, and loaded barges. Experimental conditions are shown in Table 64. Experiment LCVUCD (Table 65) shows the vertical distribution for an upbound tow and Experiment LCVDCD (Table 66) shows the vertical distribution for a downbound tow, 34 m left of the thalweg. Experiment LCVUBE (Table 67) shows the vertical distribution for an upbound tow and Experiment LCVDBE (Table 68) shows the vertical distribution for a downbound tow, 172 m left of the thalweg. Experiment LCVUAF (Table 69) shows the distribution for an upbound tow and Experiment LCVDAF (Table 70) shows the vertical distribution for a downbound tow, 318 m left of the thalweg. Results show a near uniform change in return velocity from 20 to 80 percent of the depth of flow from the bed. Results from Kampsville (Maynord and Martin 1997) show an upper zone where the return velocity is uniform and a lower zone where the near-bed velocity is retarded by the boundary resistance. The dividing line between the two zones was somewhere between 0.3 and 1.1 m above the bed for the depths used in the experiments.

Experimental Series 5—Pool Elevation 551.5

Twelve experiments (three replicates for each experiment) were conducted at a pool elevation of 551.5, with a discharge of 1,285 cms, a three-wide by five-long barge configuration, and loaded barges. The cross section is shown in Figure 77 and experimental conditions are summarized in Table 71. Ambient, maximum impact velocity, maximum return velocity, and drawdown below normal water level for each test are shown in Tables 72 to 83. The ambient velocity distribution is shown in Figure 78. The three replicate tests were averaged and one of the three was selected as being most representative of the mean of the three tests. Vector plots for each representative test are shown in Figures 79 to 90. Because the vector plots can only provide a finite number of vectors, the maximum value was not always indicated but is provided in the tables. Table 84 summarizes the position of the velocity probes used in each test.

Experimental Series 6—Dike Experiments

Pool 551.5 dike experiments

Four experiments (three replicates each) were conducted at a pool elevation of 551.5, discharge of 1,285 cms, three-wide by five-long barge configuration, and loaded barges. All ADV's were moved from their normal position at the 63-m station downstream to the 59-m mark (keeping the lateral locations the same). Two probes were positioned directly on top of the dike and slightly upstream of 59 m. A plan view is shown in Figure 91. Experimental conditions are shown in Table 85. Impact, ambient and maximum return velocity, and drawdown below normal water level for each experiment are shown in Tables 86 to 89. Experiment H59D29 can be compared to HCD292, experiment H59D47 can be compared to HCD477, experiment H59U22 can be compared to HCU228, and experiment H59U41 can be compared to HCU416 as shown in Figure 92. Velocity for an upbound tow going 4.16 m/s is shown in Figures 93 and 94 for probes 3 and 4. Velocity for a downbound tow going 4.77 m/sec is shown in Figures 95 and 96 for probes 3 and 4. The dike velocities are greater for probe 3, which is the probe located on the part of the dike with the highest elevation. All other probes had a consistent velocity from the 63-m mark to the 59-m mark. Shapes of all velocities at the 59-m mark were consistent with those at the 63-m mark.

Pool 546.0 dike experiments

Detailed velocities were measured around the Clark's Ferry dike at the 70-m mark (first dike upstream of the 63-m location) and a generic dike having a different shape that was remolded at the 70-m mark. Both dikes had Clark's Ferry dikes upstream and downstream. Five velocity meters were placed around the base of the dike and one was positioned on the top of the dike. The instruments were placed 0.6 m off the bottom of the channel and off the top of the dike (Figure 97). All experiments were conducted with six dikes placed in the model extending from the left bank to the thalweg at an angle of 78 deg upstream and spaced 304.7 m apart. The Clark's Ferry dike shape, referred to as the low dike, had a crest elevation of 539.0 on the left descending bank, to 538.0 at 85.3 m from the thalweg, to 528.8 on the thalweg. Each low dike was molded out of concrete and had a 3.0-m top width and a 1 on 3 slope down to the base at the channel bottom (see Figure 98). The generic dike shape, referred to as the high dike, had a constant crest elevation of 539.0, extending from the left bank to a point 4.7 m left of the thalweg. This elevation represents 60 percent of the total water depth at the thalweg. From this point the dike went down on a 1 on 1.5 slope to the channel bottom, elevation 528.8 (Figure 99). The high dike was formed by covering the low dike with riprap. All experiments were conducted with a pool elevation of 546.0 and a discharge of 690 cms, which resulted in an average channel velocity of 0.32 m/sec. Tow speeds relative to the ground during dike experiments were 3.82 m/sec for the downbound tow and 3.18 m/sec for the upbound tow, resulting in the same tow speed through the water for both tow directions. The tow had a three-wide by five-long barge configuration, an effective draft of 2.74 m, and a 26-deg rake on the lead barges. The sailing line was parallel to the ends of the dikes, 120 m right of the thalweg. During the experiment, velocities and direction of flow were determined for each probe location at various points in time. These points were determined by the position of the tow and its relationship to the dike. Data were recorded at eight points in time during each event. Each set of data was labeled with the position of the tow for both downbound (Figure100) and upbound runs (Figure 101). Velocities during tow passage are shown in Figures 102 to 105.

Experimental Series 7—Open River Experiment, Pool 572.7

Six experiments (three replicates of each) were conducted at a pool elevation of 572.7, with a three-wide by five-long barge configuration, and loaded barges. The open river tests required installation of vertical walls along the Clark's Ferry channel banks to simulate the larger open river depths. The Clark's Ferry water surface width is similar to the open river reach. A relatively low ambient velocity was used in the open river model tests to facilitate extraction of the tow effects, which were low because of the large section, from the ambient fluctuations. The cross section is shown in Figure 106 and experimental conditions are summarized in Table 90. Ambient, maximum impact velocity, maximum return velocity, and drawdown below normal water level for each experiment are shown in Tables 91 to 96. Velocity meters were positioned as in the Pool 551.5 experiments. Vector plots are shown in Figures 107 to 112.

Experimental Series 8—Drawdown Distribution

Detailed drawdown data were taken at six positions across the width of the channel. Results for Pool 546.0 with flow are shown in Tables 65 through 70. Drawdown data without flow were conducted at the higher pool elevations to improve the extraction of the relatively low drawdown magnitude from the ambient fluctuations. Experimental conditions for pool elevation 551.5 are shown in Table 97. Results for pool 551.5 with no flow are shown in Tables 98 to 100. Experimental conditions for pool elevation 572.7 are shown in Table 101. Results for pool elevation 572.7 are shown in Tables 102 to 104.