OPTIMUM ARRANGEMENT OF HYDRAULIC STRUCTURE COMPONENTS FOR SAFE INLAND NAVIGATION

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ABSTRACT

The aim of this study is to evaluate the effect of hydraulic structure components arrangement on inland navigation. The study was mathematically carried out by applying the SMS 2-D (Depth averaged) numerical model representing an 6.0 km straight reach symbolizing main River Nile characteristics. To identify the hydraulic and morphological features of the representative river reach, an introductory study was conducted comprising each of the main River Nile stream and each of Damietta and Rosetta branches. Therefore, the most up-to-date design specifications and techniques were applied to design the multiple function hydraulic structure components (such as gated sluiceway; hydropower plant; double navigation lock chambers; and closure dam) that related to the existing River Nile circumstances. Consequently, the induced transverse velocity components downstream the multiple functions hydraulic structure components – corresponding to different flow conditions – were examined in view point of safe inland navigation. Tree tests were applied; the first two basic and applied testing programs represented an ideal reach signifying the typical characteristic of river Nile reach, while the third validity testing program represented an actual river reach at Assiut barrages.

As the permissible cross velocity on the ship is limited to 0.3 m/s, three testing programs comprise 76 tests were carried out. Distribution of the acting transverse velocity components on the east and west lock chamber boundaries were deduced for 600 m downstream the lock. Magnitude and location of the maximum transverse velocity components were recorded for each test. This revealed that 33.3% and 79.2% of the prevailing velocity components on west and east sections respectively exceed the maximum permissible value of 0.30 m/s. This also showed a maximum velocity component of 1.508 m/s and 0.910 m/s perpendicular to the mentioned sections when the lock chamber is surrounded by the hydropower plant and the sluiceway. Evaluation of the attainable results revealed that the most efficient and optimum hydraulic structure components arrangement is fulfilled when the navigation lock is located on the eastern river followed by the hydropower plant; gated sluiceway; then the closure dam. While testing the new Assuit barrages led to conclude that the selected design would not be technically feasible and efficient to satisfy safe inland navigation.

Keywords: Safe inland navigation, Hydrodynamic transverse velocity component, SMS 2-D mathematical model, Multiple functions hydraulic structure

INTRODUCTION

Arrangement of multiple functions hydraulic structure components - such as gated sluiceway; hydroelectric plant; navigation lock; and closure dam – plays an essential role for the downstream navigation condition. This is due to the exerted hydrodynamic transverse velocity component on the ships which act as nozzle jet from the outlet structure and may cause accidences. For this reason the permissible cross velocity on the ship is limited to 0.3 m/s (Novac 1996; Romisch 1998; HRI 2002; and Mansour et al 2002). Therefore, safe inland navigation under the effecting hydrodynamic transverse pressure downstream the hydraulic structure would be the focal aspect of the current investigation.

The most common design techniques for the different hydraulic structure elements were considered. Three testing programs were mathematically carried out to define the most appropriate arrangement for the different components. The "basic" and "applied" testing programs comprised 40 and 24 testing alternatives respectively. Tests are carried out on ideal straight river reach of 6.0 km length. Those revealed that the most efficient and optimum hydraulic structure components arrangement would be achieved when the double navigation lock chambers are attached to the eastern river side followed by the hydropower plant; gated sluiceway; then the closure dam. The achieved results were then examined through the third "validity" testing program where the newly designed hydraulic structures at Assuit were utilized according to the conducted field survey measurements in September 2009. The testing program comprised a total number of 12 tests which approved the attainable results from the previous two testing programs.

PRELIMINARY STUDIES

An office study was firstly carried out to assess the ideal representative river reach. This revealed a mean value of 700 m river width which is located within the 1st reach at km 93.500 downstream of "OAD" as shown in Figure (1).

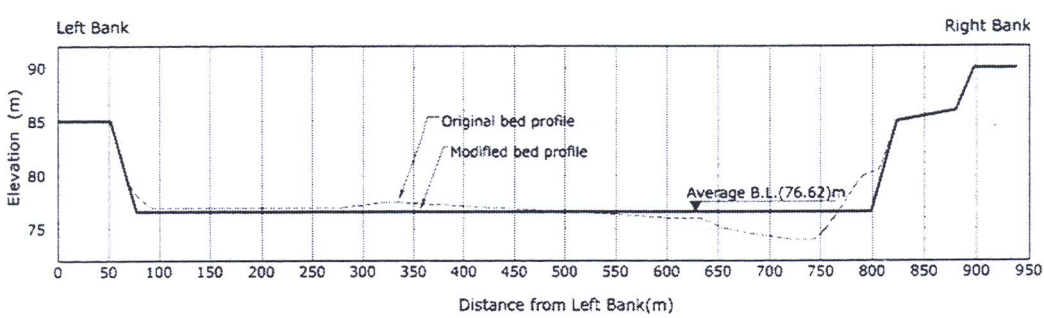

Figure 1: Adopted virtual cross section

Accordingly, the hydraulic characteristics of the ideal reach that represent the Nile River, were deduced as listed in Table (1). Design of different multiple functions hydraulic structure components, (such as navigation lock; and closure dam) were carried out (Chow, 1959; Boogaard, 1992; and PIANC and IAPH, 1997). While the sluiceway and hydropower plants were designed according to relevant specifications and the adopted procedure for the New Naga-Hammady and Assuit Barrages projects (Davis, 1952; John and Roger, 1991; HRI, 1997 and 1999). Detailed alignments for the closure dam and double navigation lock chambers were worked out. A representative river reach of 6.0 km length was considered through the conducted mathematical model tests for simulation as illustrated Figure (2).

Table 1: Adopted Hydraulic Parameters

Case No.	Flow condition	Passing flow discharge		Slope (cm / km)
		($M.m^3$/day)	(m^3/s)	
1	Minimum navigable discharge	66.4	768.5	3.70
2	Dominant flow discharge	137.0	1585.6	3.34
3	Maximum present discharge	233.0	2696.8	4.63
4	Maximum future discharge	350.0	4050.9	6.92

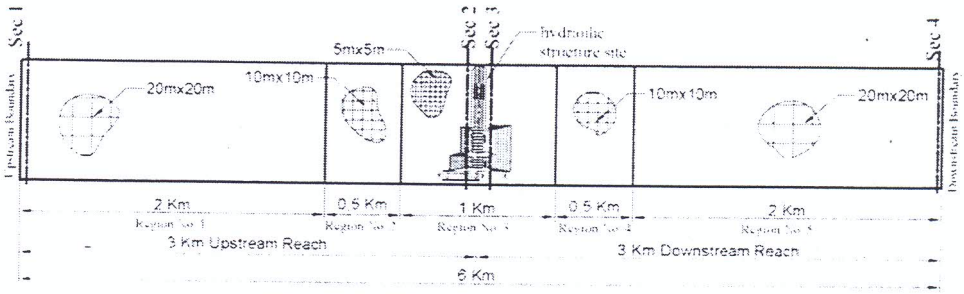

Figure 2: The Monitoring Sections

To apply the SMS 2-D model, the upstream heading up levels related to various flow discharges were worked out applying SOBEK 1-D model. Accordingly, the corresponding water surface levels to each monitoring section in Figure (2) were determined for each flow condition. The main roughness for the whole model was preliminary investigated to meet the obtained water surface profile by SOBEK. Then by trial and error the roughness factor at gate location of the powerhouse and sluiceway were adjusted to meet the outflow condition for each plant.

TESTING PROGRAMS

The study comprised three "basic; applied; and validity" testing programs which were carried out by applying the SMS 2-D mathematical model. The entire study alternatives are depicted in Table (2) which can be detailed as follows:

Table 2: Tested Alternatives for the Entire Study

Testing program	Flow case	Flow Distribution	Components arrangements	River cross section	Tested alternatives
Basic	4	2	6	1	40
Applied	3	2	2	2	24
Validity	3	2	2	1	12
Total number of the study alternatives					76

1. The 1st "basic" testing program was carried out on the ideal straight river reach of 6.0 km length with the adopted cross section that located at 93.500 km downstream the Old Aswan Dam as shown in Figure (1). The tested hydraulic structure was allocated at the middle of the ideal reach as shown in Figure (2). A total number of 36 testing alternatives - which comprised two possible flow distributions between the sluiceway and the hydropower plant for each of three flow discharges as listed in Table (3), and 6 possible arrangements for the hydraulic structure elements. While 4 more testing alternatives were carried out with

minimum navigable discharge which was limited to 2 flow distributions between the sluiceway and hydropower plant and 2 possible arrangements for the hydraulic structure elements. In Table (3), the maximum capacity of 165 million m^3/day for the hydropower plant was decided as that corresponding to 35% exceeding probability and the rest towards the gated sluiceway. While, the tested components arrangements are listed in Table (4).

Table 3: Tested Flow Discharge Cases

Flow case	Flow case	Discharge ($M.m^3$/day)			Discharge (m^3/s)		
		Total	SW	HPP	Total	SW	HPP
1	Dominant	137	137	-	1586	1586	-
2	Dominant	137	-	137	1586	-	1586
3	Max. Present	233	233	-	2697	2697	-
4	Max. Present	233	68	165	2697	787	1910
5	Max. Future	350	350	-	4051	4051	-
6	Max. Future	350	185	165	4051	2141	1910

Table 4: Hydraulic Structure Components Arrangements

Test No.	Hydraulic Structure Component Arrangement			
	1st Element	2nd Element	3rd Element	4th Element
BA	Closure dam	Gated sluiceway	Hydropower	Navigation lock
BB	Closure dam	Gated sluiceway	Navigation lock	Hydropower
BC	Closure dam	Navigation lock	Gated sluiceway	Hydropower
BD	Closure dam	Navigation lock	Hydropower	Gated sluiceway
BE	Closure dam	Hydropower	Gated sluiceway	Navigation lock
BF	Closure dam	Hydropower	Navigation lock	Gated sluiceway

2. The 2nd "applied" testing program was carried out to justify the achieved results from the "basic" testing program by considering bed configurations. The testing program was carried out on the ideal virtual straight river reach of 6.0 km length with two cross section profile shapes as shown in Figure (3). Those profiles were schematically worked out with the same cross section area to simulate the bed configurations at the case of straight and bended river reaches respectively. A total number of 36 testing alternatives - which comprised two possible flow Testing program comprised 24 study alternatives of three flow discharges with two possible flow distributions between the sluiceway and the hydropower plant; two possible arrangements for the hydraulic structure elements, and two cross section profile shapes as shown in Figure (3).

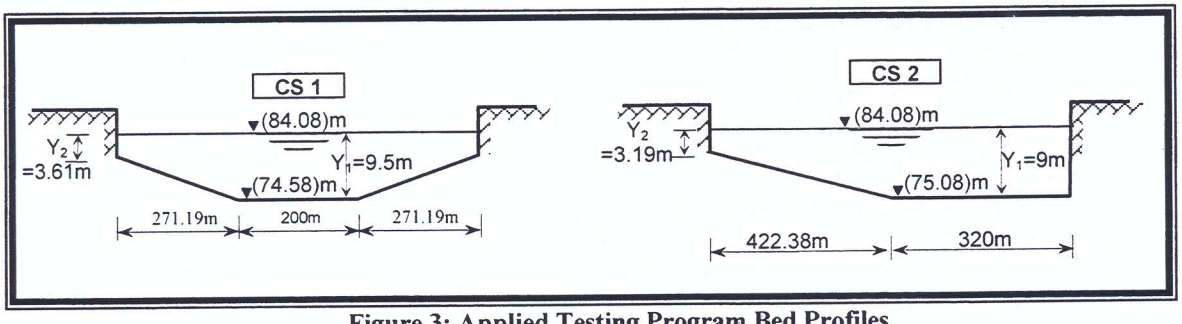

Figure 3: Applied Testing Program Bed Profiles

3. The 3rd "validity" testing program was carried out to examine the attainable results from the two previous tests with respect to the newly designed and tested hydraulic structures at Assuit shown in Figure (4). Tests were firstly carried out to calibrate the "SMS" model - according to the conducted field survey measurements in September 2009 by the Hydraulics Research Institute. As the calibration results were in good agreement with field measurements, the actual flow conditions corresponding to the dominant, maximum present and future discharges of 1124.0, 2129.6, and 4050.9 m^3/s respectively were decided. A testing program comprises three flow discharges, two discharge distributions through the sluiceway and hydropower plant through the two river branches at Bany-Murr Islands, and two hydraulic structure elements arrangements - which ultimately produce a total number of 12 tests - were carried out as listed in Table (5). The two tested hydraulic structure arrangements would be assigned as the constructed design (Con) as shown in Fig. (4) and the recommended from the current study (Rec).

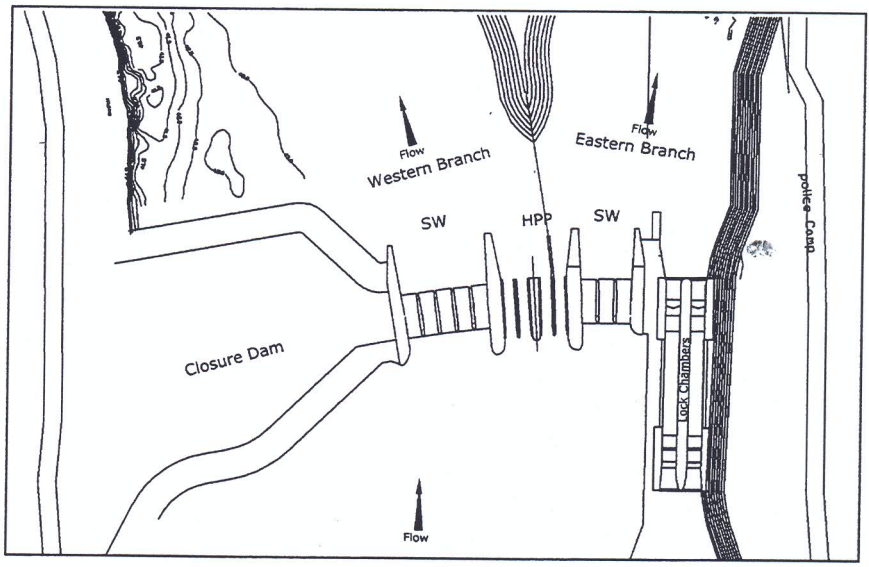

Figure 4: The New Assiut Barrages Layout Design

Table 5: Tested Flow Distributions

Flow case	Total Discharge (m^3/s)	Passing discharges (m^3/s)					
		West Branch			East Branch		
		Total	HPP	SW	Total	HPP	SW
Dominant discharge (Q_D)	1124	562.0	562	-	562.0	250	312.0
Max. Present discharge (Q_P)	2129.6	1277.8	750	527.8	851.8	250	601.8
Max. Future discharge (Q_F)	4050.9	2430.5	750	1680.5	1620.4	250	1370.4

Flow distribution between east and west river branches in the above Table was set according to the attainable physical model testing results that carried out in the Hydraulics Research Institute. The flow was equally shared between east and west branches during dominant discharge while the distribution during maximum present and future discharges were set at 40% and 60% for the east and west branches respectively. While the distribution between the hydropower plant and sluiceway was worked out to divert the maximum capacity of 21.6 million m^3/day (250 m^3/s) through each hydropower opening and the rest towards the sluiceway.

TESTING RESULTS

Analysis of the effecting transverse velocity components downstream navigation lock chambers perpendicular to the boundary cross sections (T_E and T_W) for 600 m length as illustrated in fig(5) revealed the following:

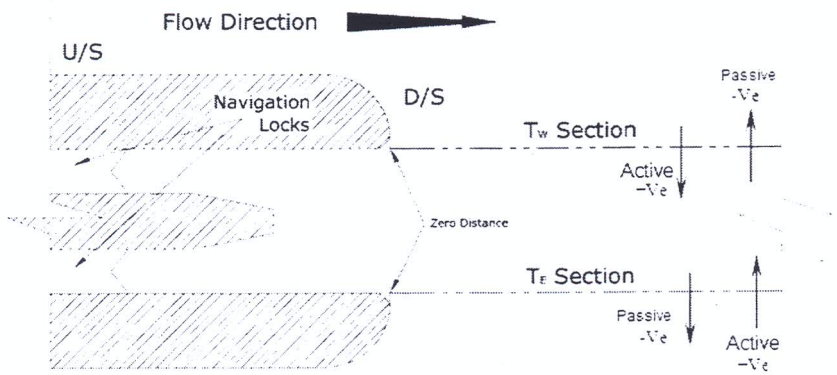

Figure 5: Location of Boundary Cross Sections T_W and T_E

Basic Testing Results

Comparison of the results was carried out for each arrangement, flow case, and boundary cross sections (T_E and T_W) for all tested alternatives. The (active) +Ve and (passive) –Ve velocity signs in the produced figures mean crossing any of the boundary cross sections (T_E and T_W) towards or outside the navigation waterway respectively as shown in Figure (5).

Considering that the double lock chamber during arrangement (BB) is surrounded by the hydropower plant at the east side and the sluiceway at the west side, the achieved results for test (BB) – as an example - with respect to the west boundary cross section (T_W) are depicted in Figures (from 6 to 8). While the produced depth average velocity pattern at the flow case 000 is illustrated in Figure (9).

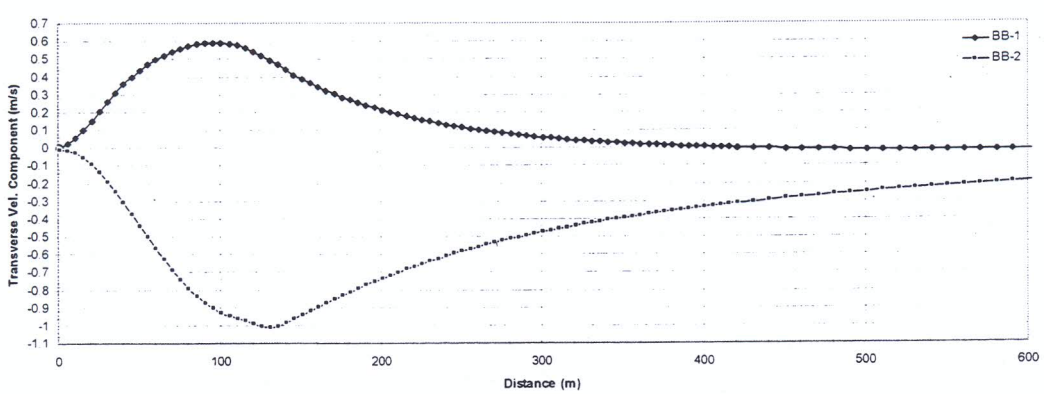

Figure 6: Comparison of Flow Cases 1 and 2 Results on Section T_W

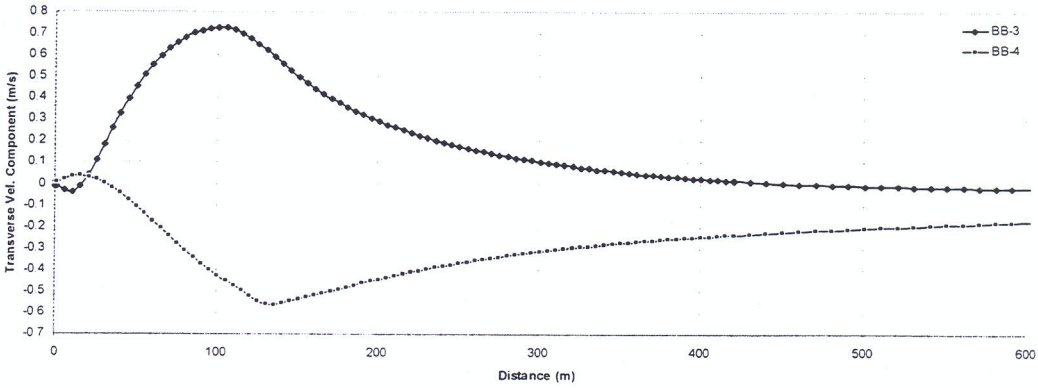

Figure 7: Comparison of Flow Cases 3 and 4 Results on Section T_W

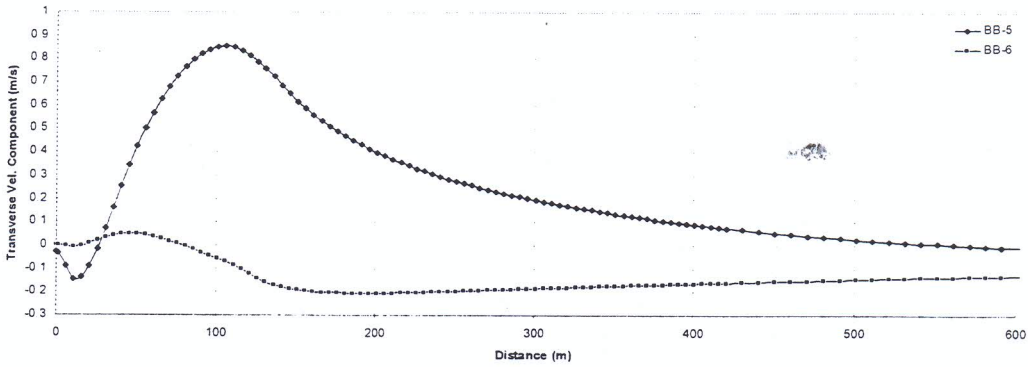

Figure 8: Comparison of Flow Cases 5 and 6 Results on Section T_W

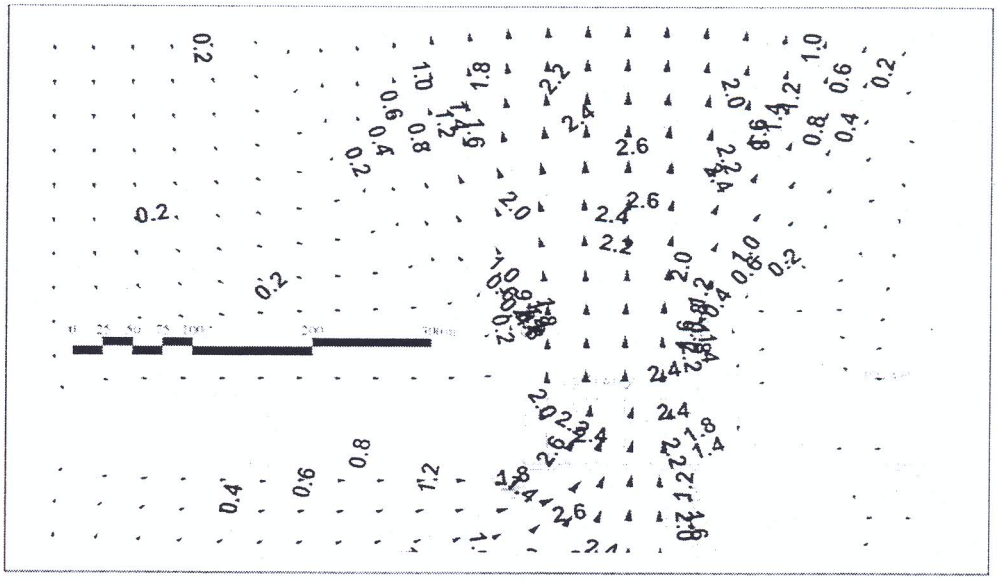

Figure 9: Depth Average Velocity Pattern at the Flow Case 000

The above Figures revealed the exaggerated effect when limiting flow discharges through the sluiceway. The maximum active transverse velocity components at this case are 0.59, 0.73 and 0.85 m/s for dominant and maximum present and future flow discharges respectively. The maximum velocity magnitudes are mainly located at 100 m downstream of the double lock chambers. Also the above Figures depict the tremendous reduction in the transverse velocity component when diverting flow through the hydropower plant and the sluiceway. The acquired results at this case revealed passive velocity magnitudes of 0.2, 0.56 and 1.03 m/s for the case of dominant and maximum present and future discharges respectively. The maximum passive velocity magnitudes are mainly located at 130 m downstream of the double lock chambers. In addition, the above Figures showed the existence of back eddies and reversed currents just downstream the lock chamber. This leads to conclude that such alternative is unsafe for inland navigation downstream the hydraulic structure. Summary of the achieved results of the acting prevailing velocities for all conducted basic tests are listed in Tables (6 and 7) and illustrated in Figures (10 and 11). The permissible transverse velocity component for safe inland navigation of 0.3 m/s was depicted in the two Figures.

Table 6: Summary of Maximum Active Velocity on Section T_E

Arrangement	BB	BC	BD	BF
Flow case	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)
1	0.005	0.956	0.742	1.204
2	1.508	0.441	0.958	0.00
3	0.065	0.993	0.547	1.337
4	1.101	0.582	1.086	0.142
5	0.162	0.957	0.38	1.411
6	0.684	0.893	1.053	0.513
Max. V.	1.508	0.993	1.086	1.411

Table 7: Summary of Maximum Active Velocity on Section T_W

Arrangement	BA	BB	BC	BD	BE	BF
Flow case	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)
1	0.220	0.591	0.00	0.00	0.358	0.00
2	0.453	0.00	0.00	0.021	0.113	0.910
3	0.207	0.726	0.073	0.046	0.526	0.00
4	0.524	0.036	0.00	0.056	0.240	0.449
5	0.185	0.854	0.202	0.155	0.711	0.075
6	0.527	0.049	0.029	0.058	0.437	0.212
Max. V.	0.527	0.854	0.202	0.155	0.711	0.910

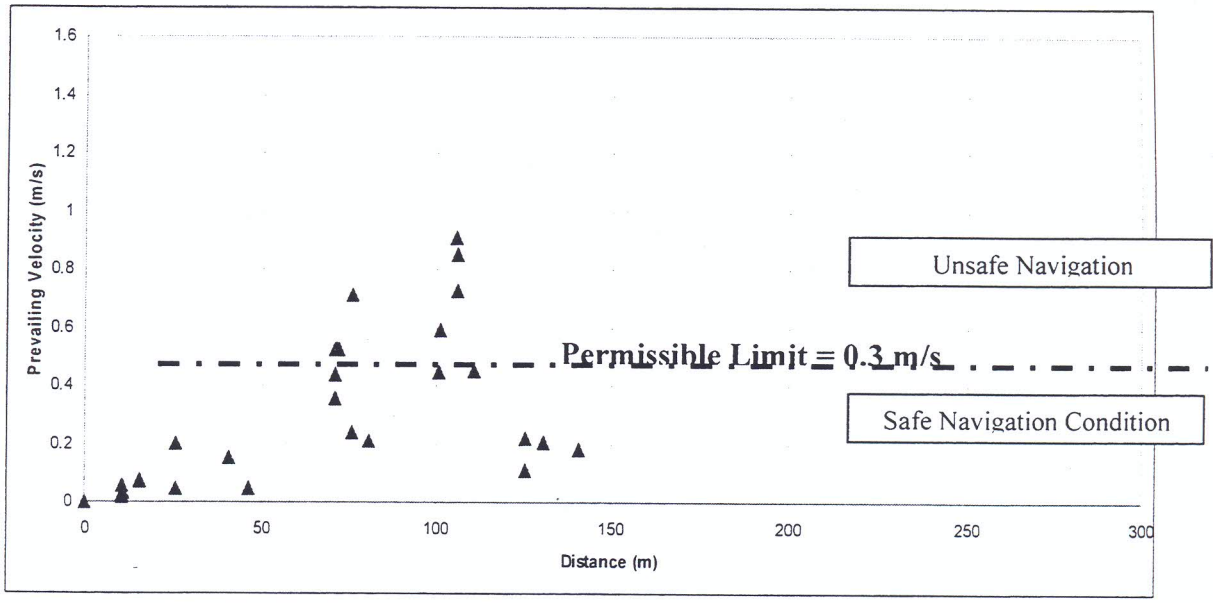

Fig.(10): Maximum Acting Transverse Velocity on Section T_W

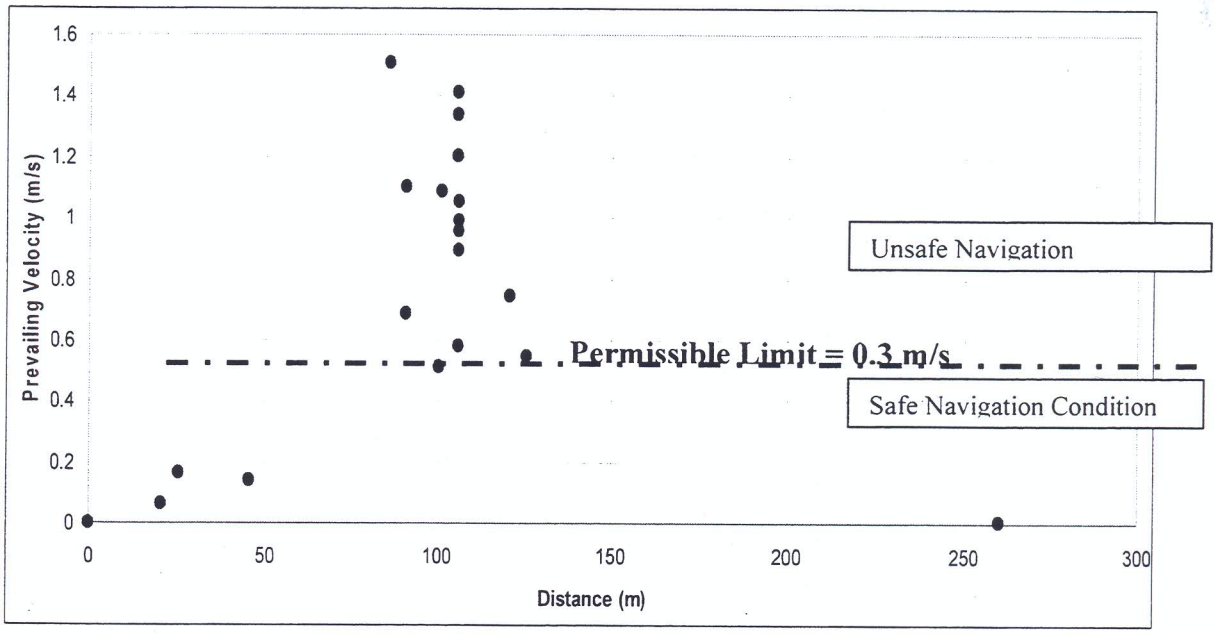

Figure 11: Maximum Acting Transverse Velocity on Section T_E

This depicted that 33.3% and 79.2% of the active transverse velocity components on cross sections T_W and T_E respectively exceed the maximum permissible value of 0.30 m/s. The maximum active velocities of 1.508 m/s and 0.910 m/s were recorded on the boundary cross sections (T_E and T_W) during BB-2 and BF-2 tests respectively. The lock chamber in this case was surrounded by the hydropower plant and the sluiceway. Analysis of the achieved results led to conclude that the most efficient and optimum hydraulic structure components arrangement would be one of the two arrangements (BA and BE). The navigation lock at those two

alternatives is attached to the eastern river side. The maximum recorded velocity during (BA) and (BE) arrangements reached 0.527 and 0.711 m/s respectively. However, as the two mentioned arrangements demonstrated reasonable velocity increase than the safe limit of 0.3 m/s, the two alternatives would be distinguished through the following applied testing program.

Applied Testing Results

This testing program intended to demonstrate the influence of bed topography – shown in figure (3)- on the effecting transverse velocity component as well as to examine the attainable results with (BA and BE) arrangements. Applying the previously mentioned system to illustrate the velocity distribution, the achieved results for cross section CS1 and arrangement (BA) are illustrated - as an example with respect to the west boundary cross section (T_W) - in Figures (from 12 to 14).

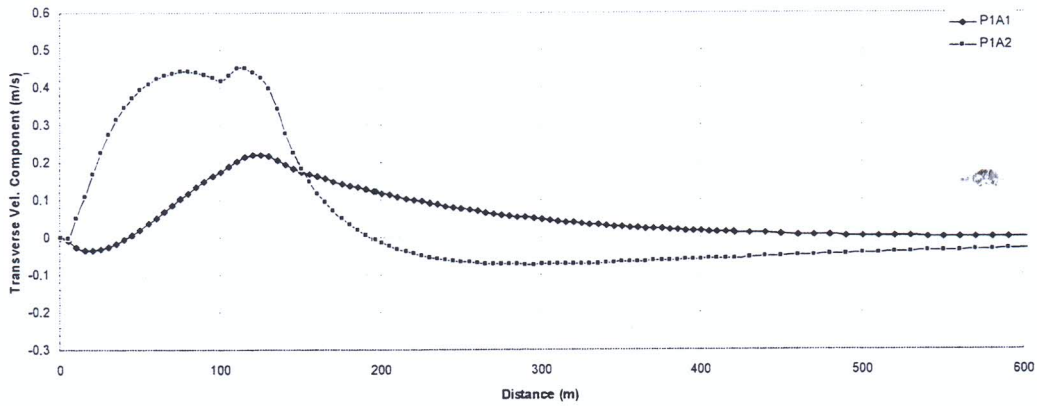

Figure 12: Comparison of Flow Cases 1 and 2 Results on Section T_W

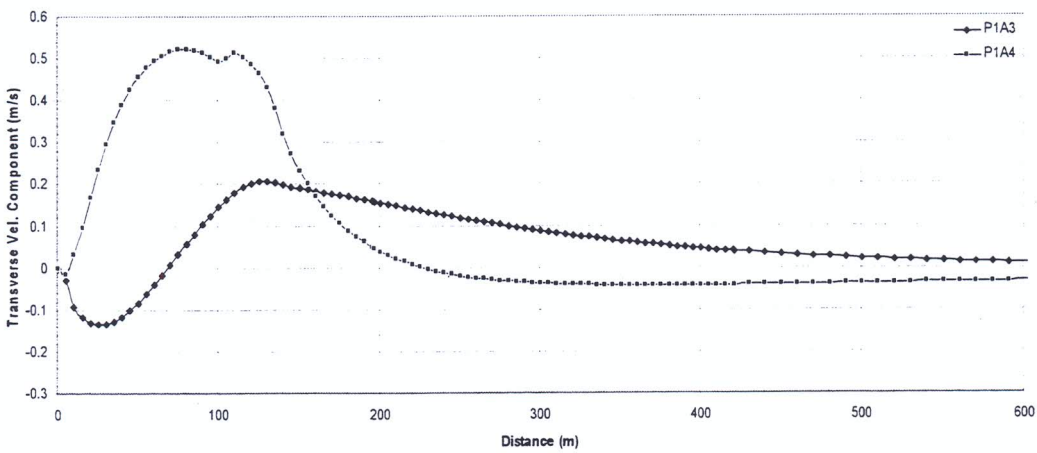

Figure 13: Comparison of Flow Cases 3 and 4 Results on Section T_W

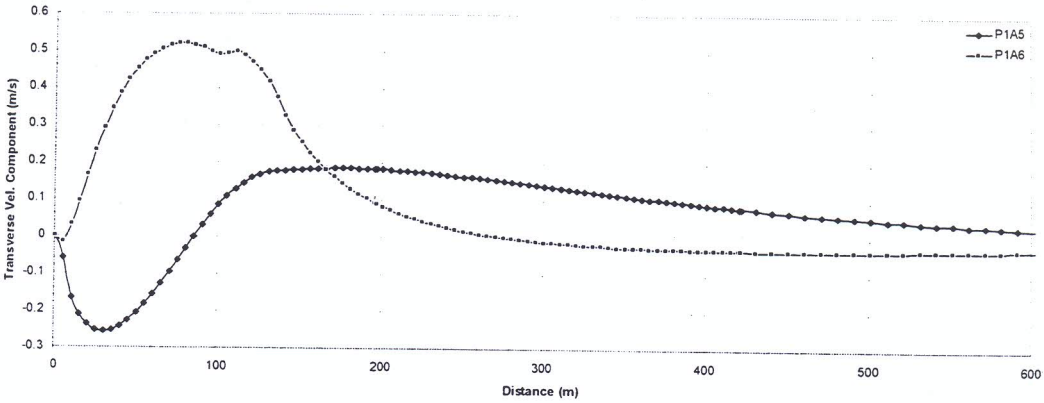

Figure 14: Comparison of Flow Cases 5 and 6 Results on Section T_W

The above Figures reveal very limited active transverse velocity components when passing the entire flow discharges through the hydropower plant. In this case, the maximum transverse velocities component of 0.22, 0.21 and 0.19 m/s corresponding to dominant and maximum present and future discharges respectively were acquired. Those low active velocities were linked by high turbulent intensity and back eddies just downstream the navigation lock. Accordingly, maximum passive velocities of 0.04, 0.14 and 0.26 m/s respectively were produced. On the other hand, sharing the passing flow between the sluiceway and the hydropower plant produces higher active velocity of 0.45, 0.52 and 0.52 m/s respectively. The maximum velocity magnitudes are mainly located at 75 m downstream of the double lock chambers. Summary of the attainable results for all conducted applied tests are listed in Table (8).

Table 8: Summary of the Applied Test Results

Cross section	CS 1		CS 2	
Arrangement	BA	BE	BA	BE
Flow case	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)	Max. V (m/s)
1	0.221	0.356	0.220	0.356
2	0.451	0.115	0.452	0.115
3	0.207	0.528	0.207	0.528
4	0.520	0.237	0.520	0.241
5	0.186	0.712	0.185	0.712
6	0.523	0.438	0.524	0.438
Max. V (m/s)	0.523	0.712	0.524	0.712

Comparison of the results for the two cross sections CS1 and CS2 as listed in Table (8) revealed insignificant variation for the same component arrangement. While the comparison with that corresponding to the basic tests for arrangements (BA) and (BE) led to conclude no materialized influence for river morphology and bed configurations. Therefore, the hydraulic structure components arrangement (BA) – where the hydropower plant is installed on the west side of the lock chambers – was considered as the most efficient arrangement in view point of safe inland navigation. For this reason the validity testing program would be carried out to verify the achieved results from the two previous testing programs. These results led to conclude that the generated transverse velocity component would be mainly influenced by the flow feature downstream the hydraulic structure rather than the variation in bed levels.

Validity Testing Results

SMS 2-D model calibration results with respect to field measurements are listed in Table (9) for the velocity measurement cross sections shown in figure (14).

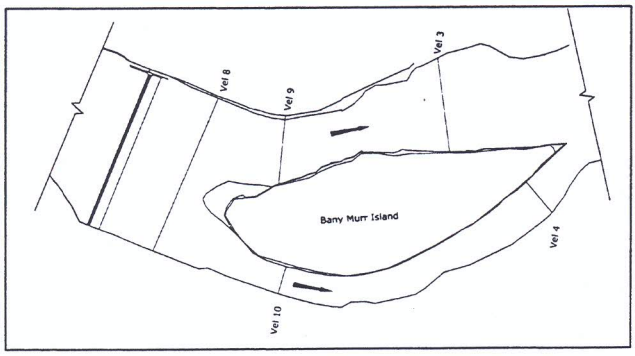

Figure 15: Location of the Velocity Measured Sections

Table 9: SMS 2-D Model Calibration Results

C.S. No.	Passing discharge (m^3/s)		Variation (%)	River discharge (m^3/s)		Variation (%)
	Prototype	SMS Model		Prototype	SMS Model	
8	1181.4	1124.2	+1.02%	1181.4	1124.2	+1.02%
9	590.7	603.4	+2.10%	1181.4	1194.3	+1.08%
10	590.7	590.9	-0.03%			
3	563.6	585.1	+3.67%	1127.2	1161.2	+2.92%
4	563.6	576.1	+2.17%			

The testing program comprised two arrangements; the constructed new Assiut barrages components arrangement (Con) which is similar to (BE) and that approved by the current study (Rec) which is similar to (BA) arrangement. The results for the two tested components arrangement at the case of passing the maximum future discharge are illustrated in Figures (16 and 17). This revealed that the active transverse velocity component would be less when limiting flow discharges through the sluiceway for the two tested arrangements. While the generated transverse velocities with (Con) arrangement for barrages components in Figure (3) are larger than that of (Rec) in Figure (17) which confirms the basic test results. Summary of all carried out tests are listed in Table (10). This illustrates velocity decrease in case of (Rec) compared to that of the constructed design (Con) which ranges between 8.0% and 41.7%.

Table 10: Summary of the Results

Arrangement Test No.	Constructed Max. V (m/s)	Recommended Max. V (m/s)	Percentage decrease (%)
Q_DD_1	0.355	0.304	14.4%
Q_DD_2	0.351	0.323	8.0%
Q_PD_1	0.319	0.273	14.4%
Q_PD_2	0.346	0.273	21.1%
Q_FD_1	0.334	0.231	30.8%
Q_FD_2	0.415	0.242	41.7%

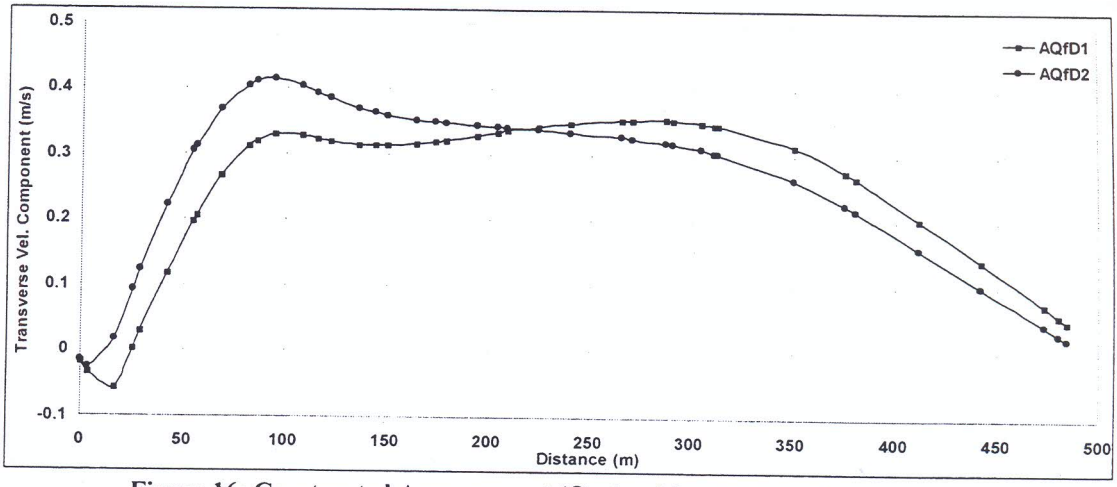

Figure 16: Constructed Arrangement (Con) at Max. Future Discharge

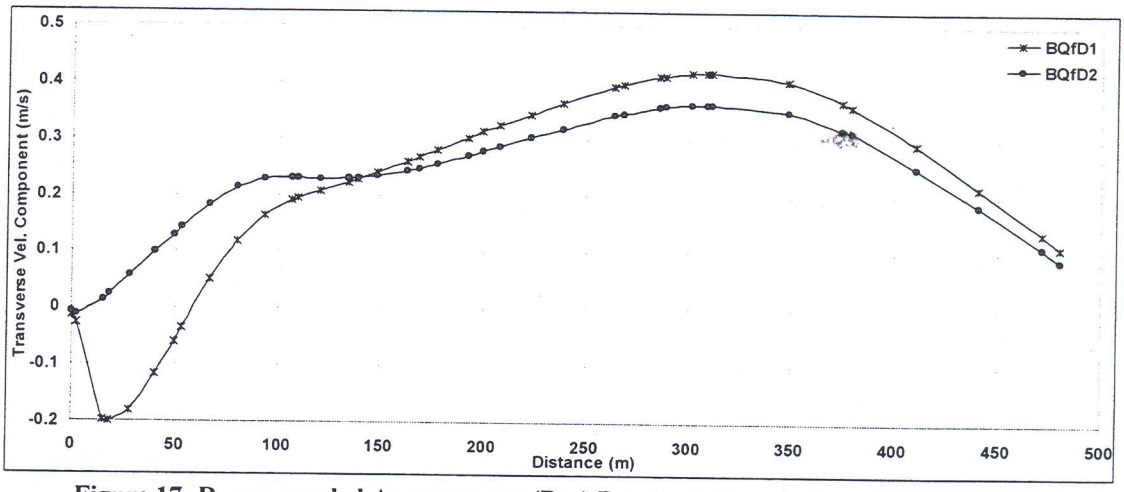

Figure 17: Recommended Arrangement (Rec) Results at Max. Future Discharge

CONCLUSIONS AND RECOMMENDATIONS

- The most efficient and optimum hydraulic structure components arrangement - in view point of safe inland navigation – is arrangement (A) where the navigation lock is followed by the hydropower plant; gated sluiceway; then the closure dam.
- Testing "SMS" 2-D model for the existing river conditions confirmed that the constructed arrangement of the new Assuit barrages components is not technically feasible and efficient in view point of safe inland navigation.
- Variation of bed configuration upstream the hydraulic structure has no influence on the generated transverse velocity component downstream the hydraulic structure
- The applied design procedure for the gated sluiceway and hydropower plant should be included in the design of the hydraulic structure course in Egyptian universities.
- Employing "SMS" 2-D (depth averaged) mathematical model can be considered as beneficial and competent tool to manage and provide multi dimensional solutions for solving river engineering problems.

- Establishing the most economic and technically feasible arrangement for the hydraulic structure elements should be elaborated in such a way as to minimize the effecting transverse velocity components perpendicular to the inland navigation units.
- The applied procedure is highly recommended to be carried out to implement real project by considering the existing flow features, bed configurations, and the actual river surrounding boundaries.

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