RESEARCH NOTE

HYDRAULIC MODEL STUDIES OF NON-SYMMETRIC Y-BRANCHES IN KARUN-I

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Abstract Power stations with high heads are nowadays almost without exception designed so as to have one pipeline, or a few pipelines, supplying the water to the turbines. The penstocks is connected to a distributor which has the task of distributing the flow with the lowest possible losses of energy to the individual turbines. The function and location of this section of the plant make it understandable that its safety is regarded as a matter of outstanding importance. Careful selection of materials, followed by continuous and extremely meticulous inspections of work-pieces and production processes enable the manufacturer to rule out unwarrantable risks as regards materials. Furthermore, well-substantiated method of computation and experimental stress investigations make it possible to control stresses occurring in the complicated bifurcations. Thus adequate safety and economical design of the construction are ensured by suitable matching of stress levels to the properties of the materials used. The experimental work included over the two of three types of different sickle rib geometries on non-symmetric wye-branch upon certain critical flow conditions are presented. The objectives of the studies were to determine the influence of the geometry and size of sickle rib on head losses in Karun I conical wyes. The prototype of wye consists of six conical at the main and three extended cylindrical, one for inflow and two for out flow. The scale of model is 1:25 which three types of sickle ribs can be assembled on the model.

Key Words Hydraulic Model Test, Non-Symmetric, Y-Branch, Sickle Rib Geometry, Pressure Distribution, Flow Velocity

چکیده امروزه در طرح نیروگاههای برق آبی تحت ارتفاعات ریزش بالا، جهت انتقال آب به توربین از یک یا چند آبراهه استفاده می‌شود. در این آبراهه‌ها جریان آب پس از تونل فشار، توسط چند شاخه با حداقل افت انرژی تقسیم شده و به هر یک از توربین‌ها می‌رسند. در این بخش از طراحی، شرائط و موقعیت نیروگاه از نظر اطمینان بخشی و کارآئی اهمیت ویژه‌ای دارد. انتخاب دقیق و مناسب مواد که در ارائه آن شرائط خاص نگهداری قطعات و امکان برقراری عملکرد سیستم را بدنبال دارد، سازنده را در جهت کاهش تهدید و صدمه پذیری سیستم یاری می‌نماید. مضافاً روشهای متکی بر اساس و اصول محاسباتی و تجربیات اندازه‌گیری آثار تنشی، پیش بینی و مهار آثار تنشی در شاخه‌ها را امکان‌پذیر می‌سازند. بر این اساس اطمینان کافی در یک طرح بهینه در یک فرآیند ساخت مناسب بوسیله تطبیق صحیح ترازهای تنشی و شرائط رفتاری مواد بکار گرفته شده حاصل می‌گردد. کارهای تجربی حاصله از آزمایش سه نوع صفحه تقویت اصلی فاق با هندسهٔ متفاوت بر روی دو شاخنه نامتقارن و شرائط بحرانی جریان ارائه شده است. هدف از این تحقیق بررسی اثر هندسه و اندازه صفحه تقویت یاد شده بر روی افت انرژی در دو شاخه بکار رفته در پروژه سد کارون I می‌باشد. ساختمان نمونه اصلی دو شاخه شامل شش قسمت مخروطی ناقص در دو بخش اصلی دو شاخه بوده که توسط سه لوله استوانه‌ای امتداد یافته که شاخه اصلی جهت ورود و دو شاخه کوچکتر برای خروج جریان آب می‌باشد. مقیاس مدل بکار گرفته شده ۱ به ۲۵ بوده که سه نوع مختلف از صفحه تقویت فاق بر روی آن در سه مرحله نصب گردیده است.

1. INTRODUCTION

The Karun I second power station project is a hydroelectric power plant which will have a total installed capacity of 1000 MW split between four units. The project is located at the mid-length of the Karun river near Masjid-Solaymaan city in Islamic Republic of Iran.

The penstocks and pressure shaft for the second power station were driven as tunnels, with finished internal diameters of 10 m. at starting of steel lining, 7.8 m. before bifurcation, and 5.1 m. after Y-branch up to turbines, respectively. The maximum static head for these developments as permanent loading was 230 m. including water hammer effects. The construction of surface penstocks from intake at elevation 490 (meter above sea level) up to 395 (meter above sea level) is made of concrete and lower than this level down to the butterfly valve and turbine at elevation 355(meter above sea level) is steel lined [1]. These steel linings start with 5 m. long diffusers changing of 10 m. inner diameter to 7.8 m. in conic shape. The next component is a 81.47 •, 40 m. long bends and after 18 m. long straight pipe, a Y-branch make the flow bifurcation at both water ways. Two bifurcated tunnels, 30 m. straight and one 40 m. bend pipes, both having 5.1 m. inner diameter, connect the Y-branch to the turbine valve. The total length of each line is nearly 135 m. and the total weight of both steel lines is 2100 tons. Figure 1-a shows a general waterway side view. Figure 1-b also, shows right and left waterways plan where they have still lining.

The geometries of Y-branches including sickle ribs and main stiffener are shown in Figures 2, 3 and 4.

In recent method of design, the non-symmetric geometry of distributor pipes, which mainly used for hydro-power plants are preferred [8]. Accordingly, most often a crescent shaped, internally situated reinforcing ribs, try to be free from bending stresses are used instead of conventional external collar reinforcements. The main advantages of this type of geometry are due to increase safety, reduced head losses, and smaller space requirements. The calculation, design and construction of penstocks require special knowledge and experience in the field of development of hydro-power stations. In design of the high diameter Y-branches, the technical considerations relative to the manufacture, transport and erection can play a decisive part in the choice of the economical solution.

The preparation of the project must be conducted according to the rules of the art and by taking the latest available technical advantages into account [1]. The inquiry shall define the site and the type of penstocks.

At the power stations including turbine or pump operations, the flow of water must receive the minimum head loss. The optimum hydrodynamics shape of the branch pipes are generally determined both by numerical modeling and hydraulic model tests.

2. FLOW CONDITIONS

To minimize the head losses, usually, the sections in the main branch near the bifurcate are increased as in a diffuser and from there, by applying conically shaped outlet branches, flow is accelerated in order to avoid eddies. Also, this shape of distribution pipe permits the application of reinforcements. Moreover, the following components contribute towards keeping the losses low:

- Enlargement of gross section in the branch zone leads to low velocity of flow and consequently, much lower head losses.
- The pronounced conical shape of the regions permits the use of a small reinforcement sickle resulting in only slight flow disturbance even at quite unsymmetrical distribution ranges [8].
- Smooth deviation of the flow towards the lateral branching causing no eddies [8].

These specifications recommended to be valid for both directions of flow. However, these are important in a storage plant either with pumping or generating operation. Considering the above items in design, it has been proved that head losses in non symmetric

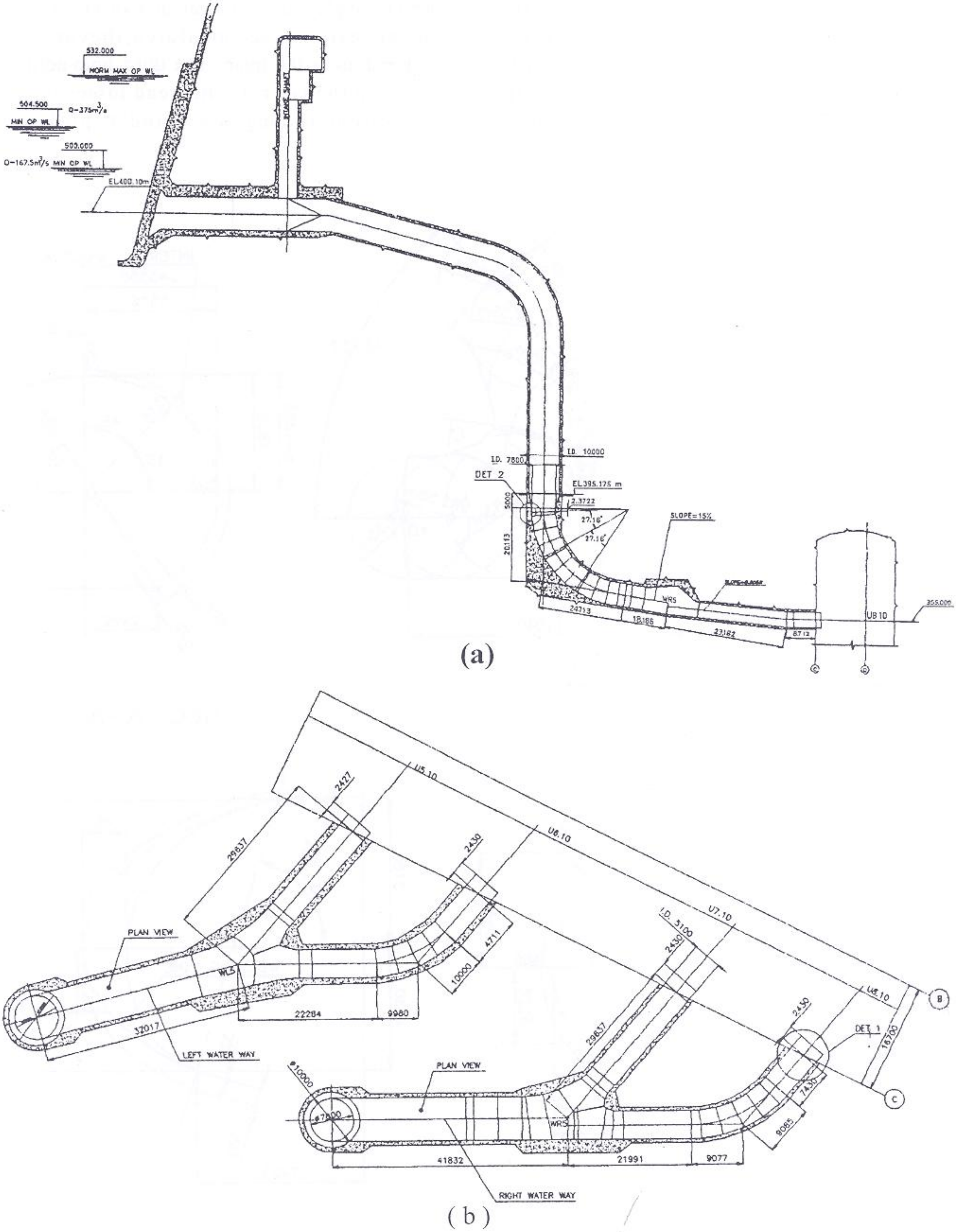


Figure 1. (a) General waterway side view and (b) Right and Left waterway plans.

Y-branches are lower in comparison with the conventional collar type [8]. This is valid, particularly for the operation near the economically most important hydraulic symmetrical range. Usually, two of the limbs which roughly are collinear and of either equal or unequal cross-sectional area, they are often referred to as the main. The third limb normally is called the lateral. The head losses in total pressure in the legs are found by projecting

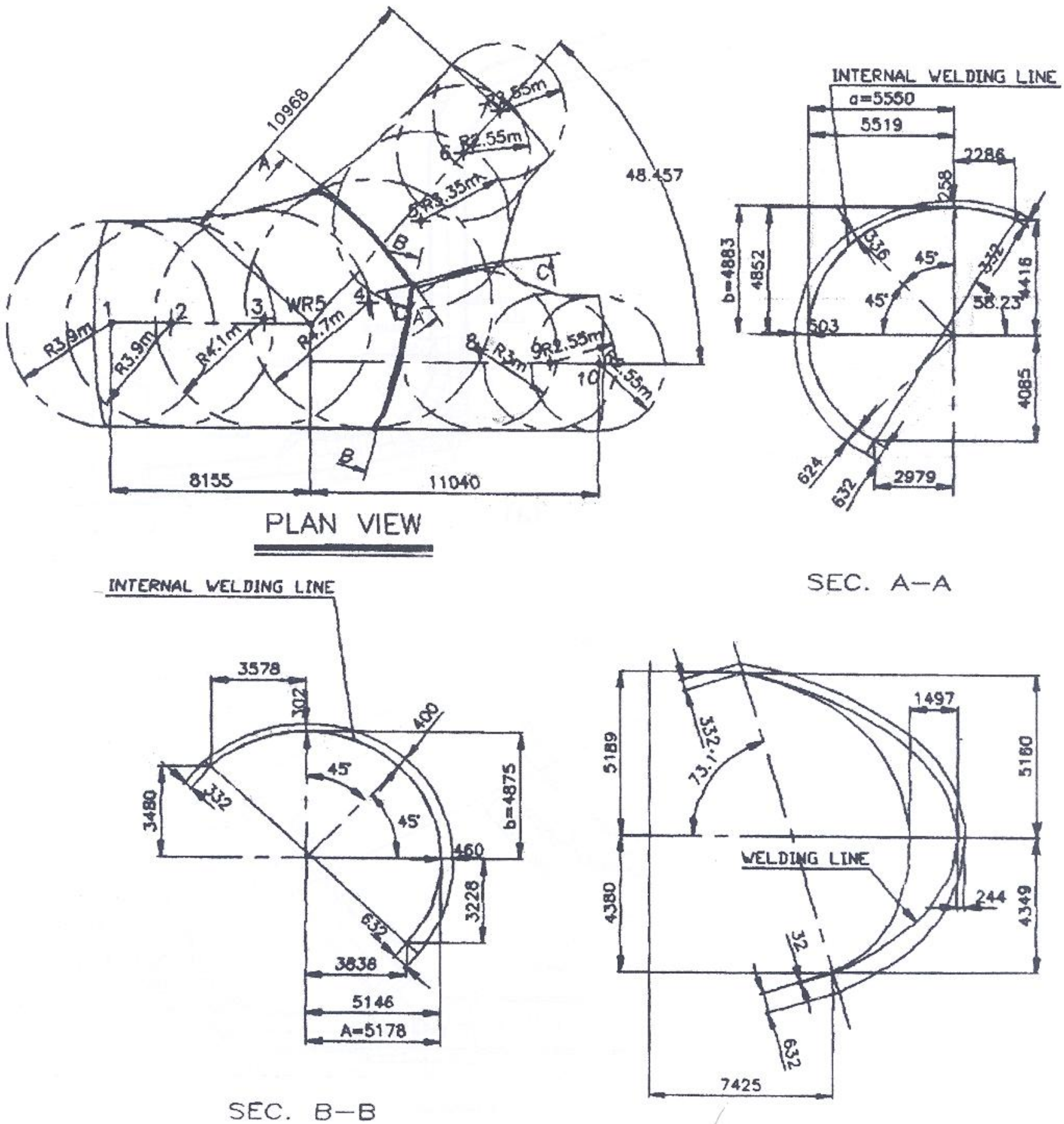


Figure 2. Right Y-branch geometry (continued in the next page).

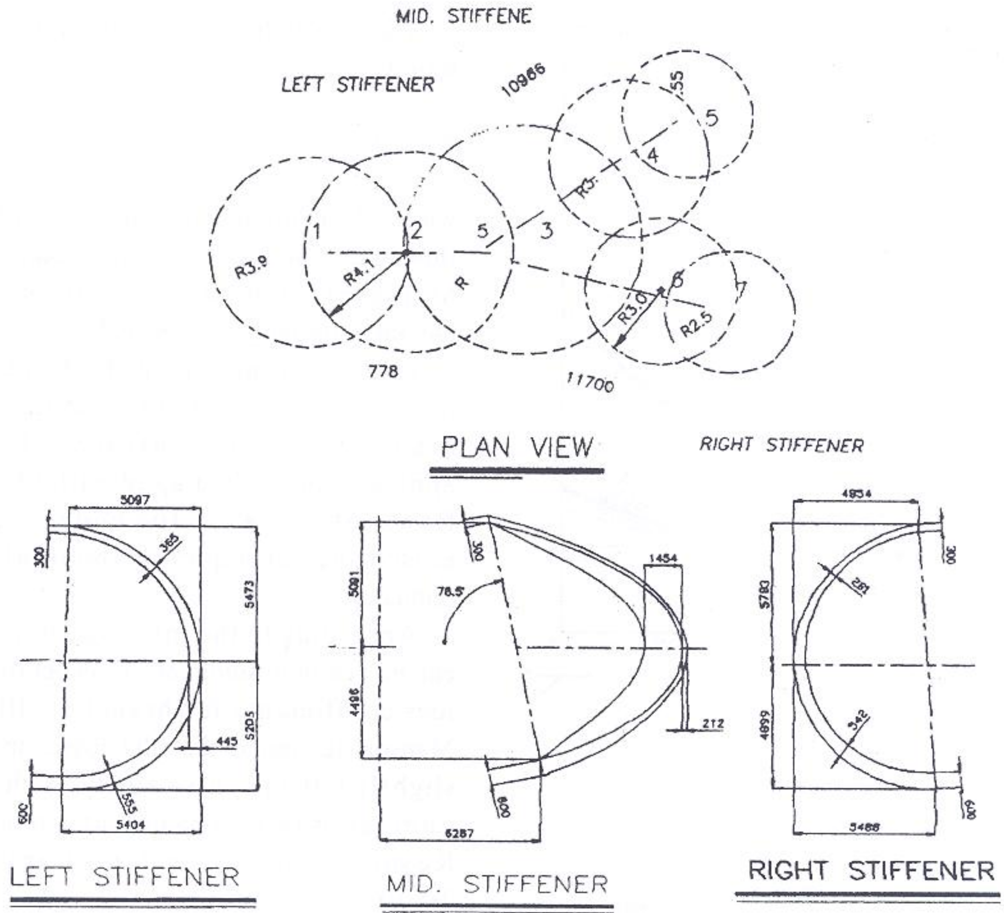


Figure 3. Left Y-branch geometry

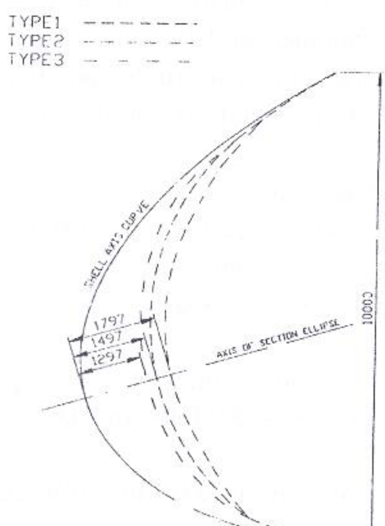


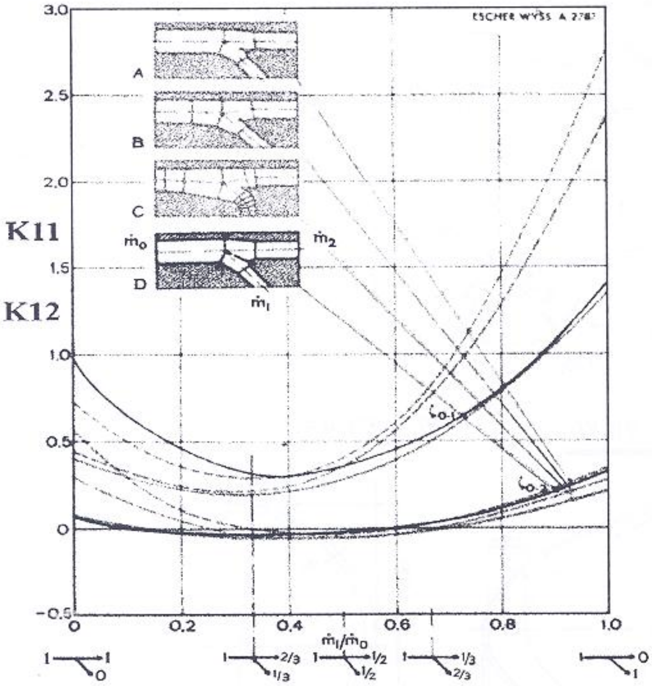
Figure 4. Sickle rib in three positions.

back to the datum plane that fully developed total pressure gradients which ultimately arise well away from the influence of the branch.

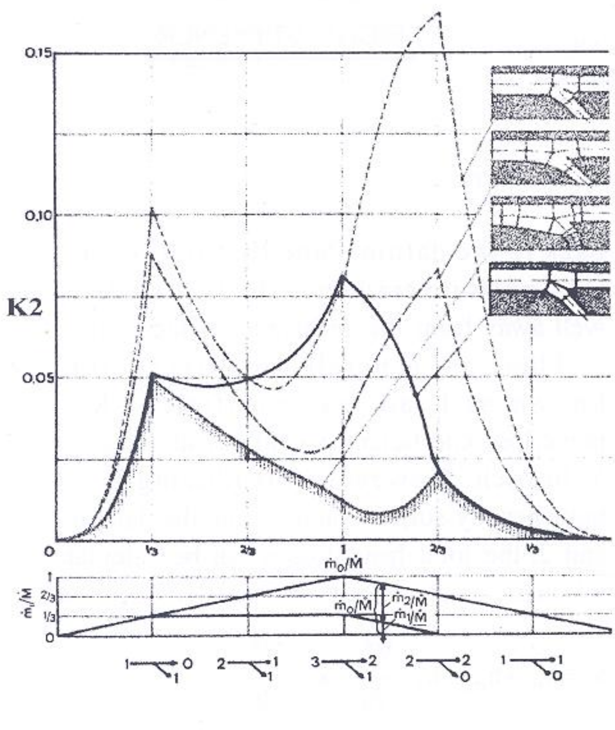
There are generally two loss coefficients known as head loss coefficient K_{11} and powerloss coefficient K_{12} affect the total loss in Y-branch. However, introducing the main branches by suffix ∘ and 1 and the lateral by ∘ and 2, the total head losses can be calculated as follows:

$$h_{\circ}=h_{\circ 1}+h_{\circ 2}=k_{11}\frac{V_{\circ 1}^{2}}{2g}+k_{12}\frac{V_{\circ 2}^{2}}{2g} \quad (1)$$

where, $V_{\circ 1}$ and $V_{\circ 2}$ are the velocities in branch 1 and 2. Figure 5-a shows the variation of K_{11} and K_{12} versus the rate of discharges in branches.



(a)



(b)

Figure 5. (a) K11 and K12 and (b) K2 versus discharge.

The power loss coefficient T is calculated as follows:

$$T=K_2M\frac{V^2}{2g} \tag{2}$$

where M is maximum time rate of inlet mass flow and V stands for velocity corresponding to M. Figure 5-b shows the varition of K_2 versus the rate discharges in branches.

In order to minimize the head losses, it is necessary to increase the sections in the main branch near the bifurcate. Therefore, by applying conically shaped outlet branches, the flow is accelerated, the eddes is going to be erased and consequently the total head loss is reduced.

According to the investigations carried out eht no rebmnu sdlonyeR fo ecneulfni eht tuoba loss coefficients for branches, Blaisdell and Manson [2] found that the losses in Y-branches slightly but insignificaintly as the Reynolds number was increased up to a maximum Reynolds number tested of approximately $2 \cdot 10^5$•

However, as the Reynolds numbers for most of the experiments reported [3-6] were typically of the order 10^5, the data might be expected to apply with reasonable confidence down to Reynolds number of 10^4.

The calculated head losses for Karun I pressure shaft, penstocks, and Y-branch are as follows:

For concrete bend:

(• = bending radius, • = 14.036•, and D = 10 m.) h_{b1} = 0.096 m.

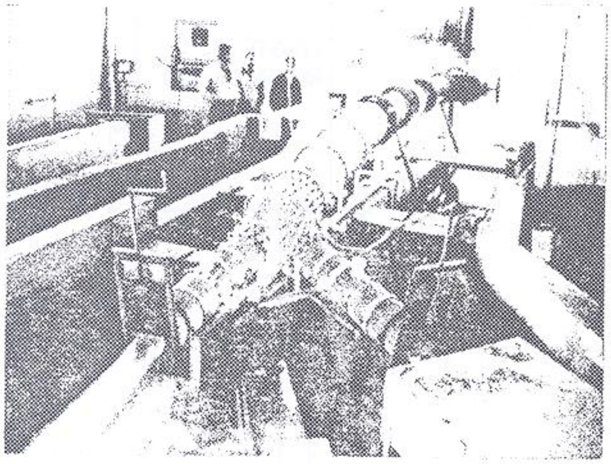
(• = 28 m., • = 75.964•, and D = 10 m.) h_{b2} = 0.2075 m.

For steel made bend:

(• = 28 m., • = 81.469•, and D = 7.8 m.) h_{b1} = 0.572 m.

Therefore, the total value of head losses in bends is equal to 0.875 m..

The straight steel pipe frictions (two parts),concrete lining pressure loss, diffuser, and Y-branch pressure losses are: 0.083, 0.45,



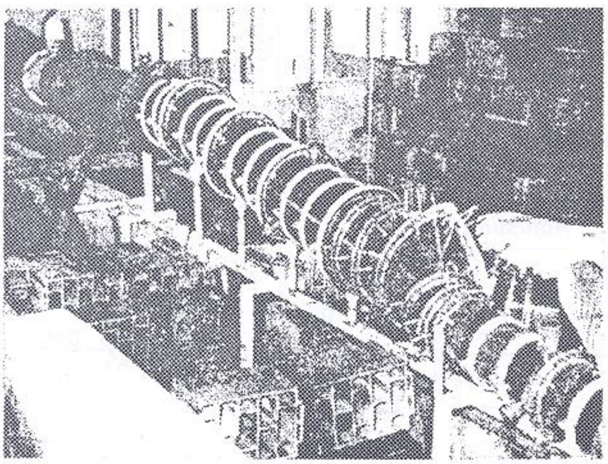


Figure 6. The model and extended pipes in labratory.

4.5484, 0.22, and 2.084 m., respectively, [9]. Therefore the total value of head losses is equal to 9.401 m.. Consequently the percentage of head loss will be equal to 5.31%, which is fairly low and acceptable. The obtained head loss value is based on normal analytical calculation. Whereas, the accurate value may be computed through numerical methods such as finite element or finite difference methods.

3. MODEL SPECIFICATIONS

The model consisted of the extended inlet pipe, wye, and two outflow extended pipes, aligned with theodolite in a horizontal plane and nonsymmetrical to the longitudinal center line. Figure 6 shows the model and extended pipes in laboratory. To provide the possibility of dismantling for new sickle rib, some sections are jointed and fitted with flanges of equal diameters. Thereafter, the joining pipe ends were machined to have equal inside diameters and to eliminate any offsets at joints. The pipe ends to be jointed with the wye also were machined and fitted to have an inside diameter equal to that of the wye. During assembly the flanged joints were aligned by hand to eliminate any offset. Thereafter the joint between wye and the main pipe was aligned by means of locating-pins to ensure a smooth fit.

As stated earlier, the scale of this model is 1:25. Therefore, the real head pressure in prototype which is 177 m. (excluding water hammer effects) is reduced to 6.6 m.. The side view of hydraulic model test is shown in Figure 7.

Fifty eight pipe type piezometers are installed on nine segments of wye to measure the pressures at different points of model. Figure 8 shows the general location of nine segments of both wye branches and the position of installed piezometers. Further to the above, 58 piezometers, six piezometers plus one velocity meter installed at each of three inflow and outflows sections. Figure 10 shows the arrangement of second sets of piezometers at the inflow and outflow sections.

4. TEST PROCEDURE AND RESULTS

To cover most of the critical cases and providing the maximum head loss effects in Y-branch a free opening at outflow for each sickle rib is considered. In each case, inflow and outflows and also dynamic pressure containing 2000 values at 70 seconds for each piezometer are measured and recorded.

Two main characters of separation and

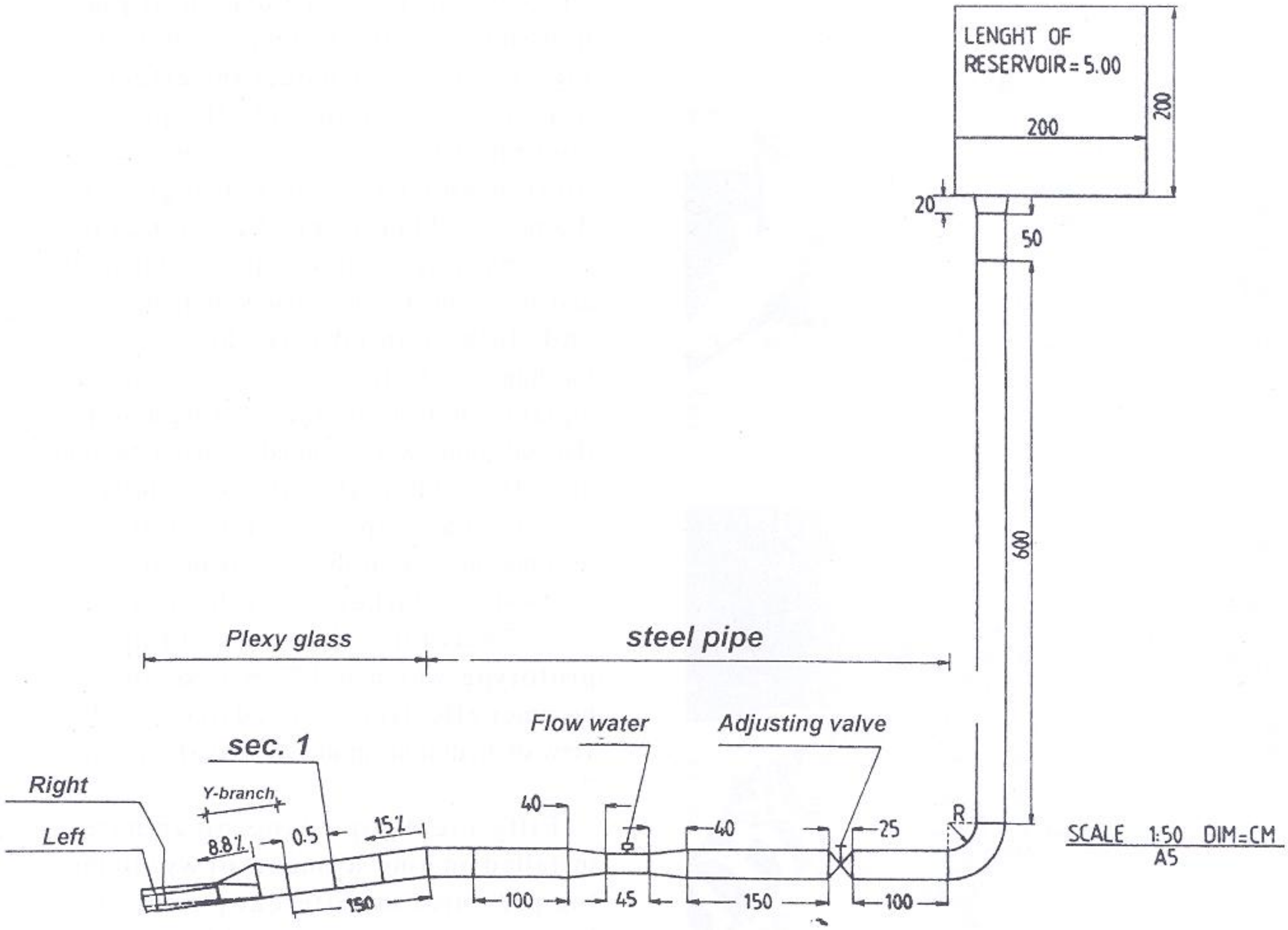


Figure 7. The side view of hydraulic model.

cavitation were consciously under control, therefore at the suspicious location near the sickle rib the needed piezometers are located. However, the possibility of cavitation through pressured waterways is little. To provide a better velocity distribution at inflow section, it is extended by for pieces of pipes, an adiusting valve and a flow meter as shown in Figure 6. This condition also, is provided at outflows.

The first test is for the first sickle rib with a maximum width of 71.9 mm at nearly midpoint inside wye. Upon the opening conditions stated in Figures 9, 10 and 11 the measured dynamic pressure oscillation are shown for different piezometer numbered in different Segments 1, 2, 3, 4, 5 and 6 after 1, 2 and 3 seconds. For each set of result, a table containing the maximum, minimum, and average pressures, standard deviations and coefficient of variations of each piezometer are presented.

The necessary hydraulic information including opening condition of outflows, inflow and outflow velocities, all upon nine cases of tests are stated in Table 1. Table 2 contains the velocity ratios of outflows and inflow, average pressures at inflow and outflow sections, piezometric pressure height based on reference line, total energy, pressure difference between in flow and outflows, coefficient of head losses in branches [8] upon nine stated cases.

Tables 3 and 4 are stating similar results as Tables 1 and 2, but while the stiffener 2 is

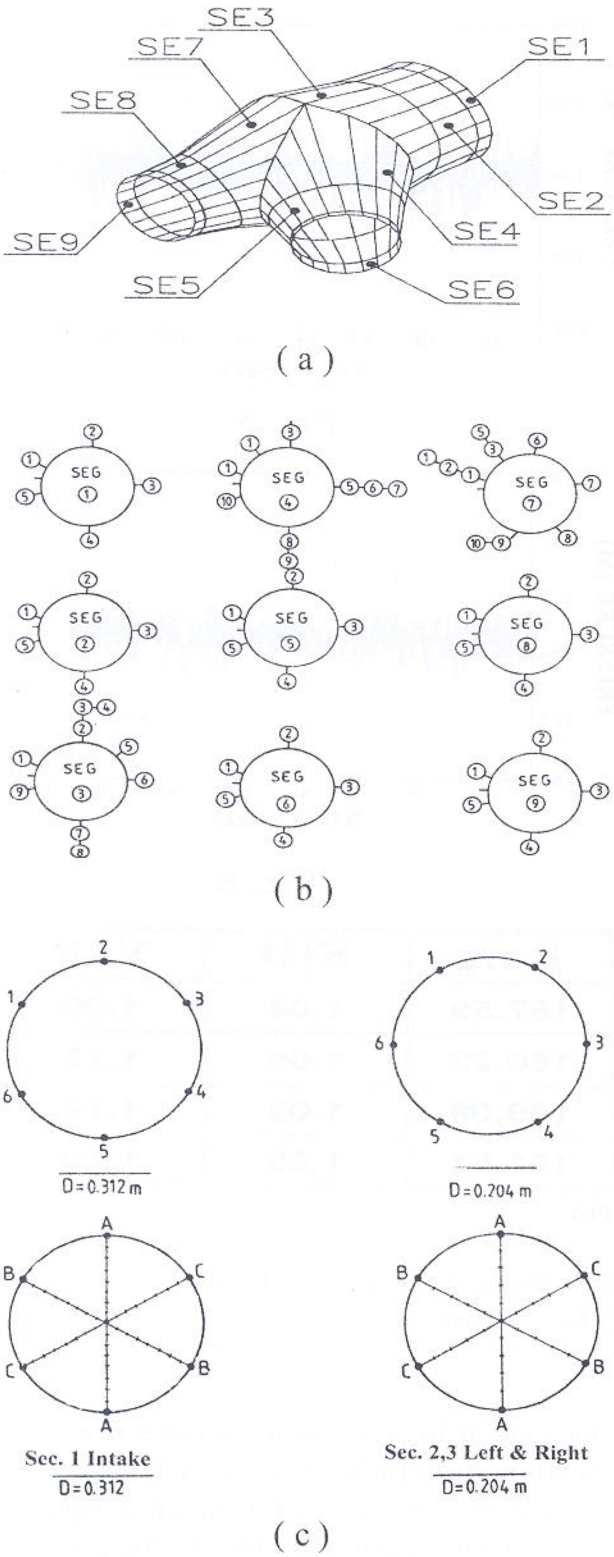


Figure 8. The location of (a) Nine segments in Y, (b) Installed piezoneters and (c) Piezoneters at inflow and outflows.

installed on the model.

Variations of the coefficient of head losses through branches using first stiffener obtained by model and normal calculation are presented in Figure 12. Similar presentation of results are provided for the second stiffener. Figure 13 shows variation of the coefficient of head losses in this case.

The comparison of the coefficient of head losses for different tests with the first and the second stiffeners are shown in Figure 14.

For a stronger justification, the obtained results are compared also with results carried out through the method presented by Williamson et al. [7] and Escher Wyss [8]. Figures 15 and 16 shows these comparisons for left and right branches respectively. The comparison shows that the model results are closer to Escher Wyss results rather than Williamson. The differences of results are mainly due to different geometry of wyes. Also Williamson's results are obtained upon simple wyes without using any conical transitions which are certainly not true in our cases.

5. PRESSURE DISTRIBUTION ON LINER

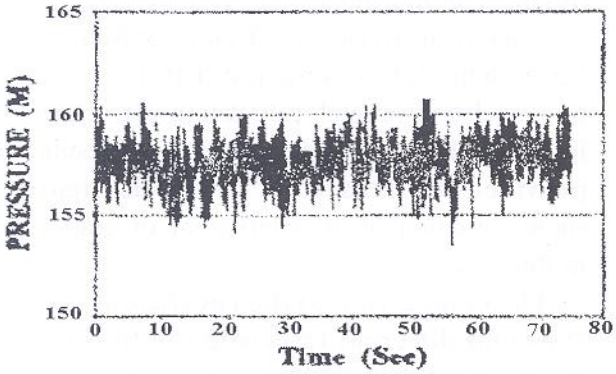
To provide internal pressure distribution on liner, three different cases of tests are considered upon the choice of the two different stiffeners. These cases are defined as follows:

(a) full opening of both outlet branches while both outflows are equal to 72 ℓ /s.

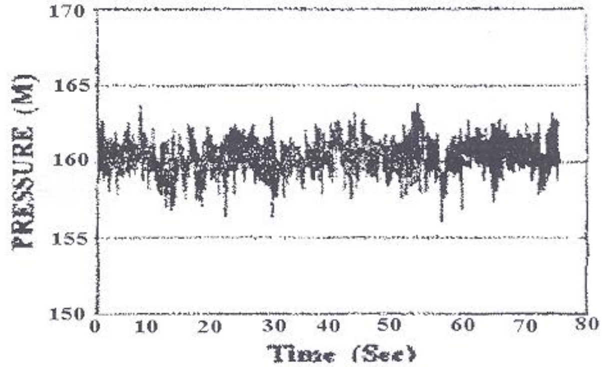
(b) right branch is fully closed while the left is fully open.

(c) right branch is fully open while the left is fully closed.

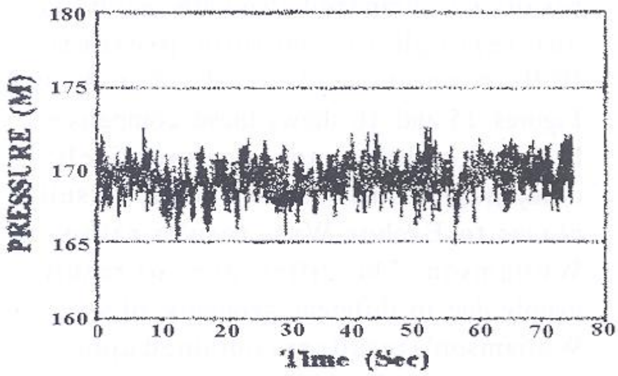
However, only the results of case (a) are presented here upon measuring pressure in piezometers numbered 1 to 10. The average piezometric pressure on each section as arestated in two cases of stiffener 1 and 2 in Tables 5 and 6 respectively. The comparison of two piezometric lines through right and left



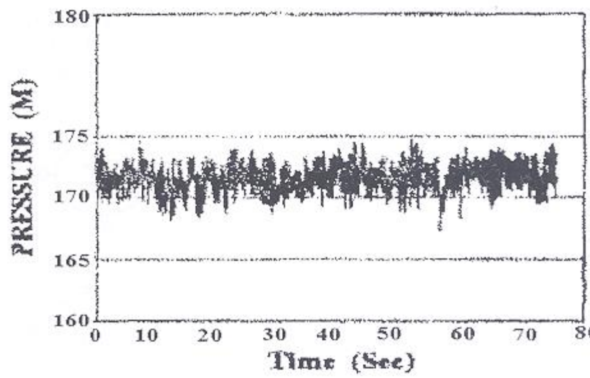
Piz. 2



Piz. 3



Piz. 5



Piz. 6

PIZ No.	P max	P min	P avg	STD	VAR
2	160.66	153.49	157.59	1.04	1.09
3	163.89	156.05	160.23	1.06	1.12
5	172.43	164.86	169.09	1.09	1.19
6	164.78	157.30	161.51	1.05	1.10

**For Pizometer Location See Drawing. No.*

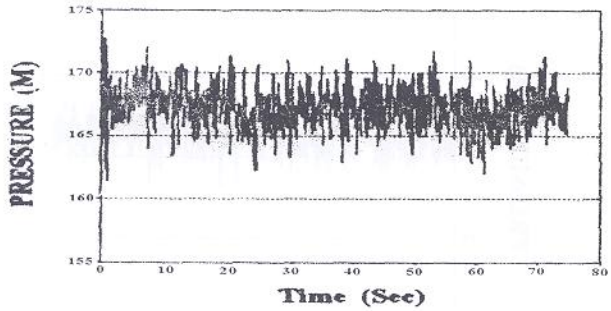
Figure 9. Dynamic pressure at Section 1 stiffener left branch: 3/4 openright branch: open Q(L) = 260cms Q(R) = 342 cms.

branches for the cases of the first and the second are presented in Figure 17.

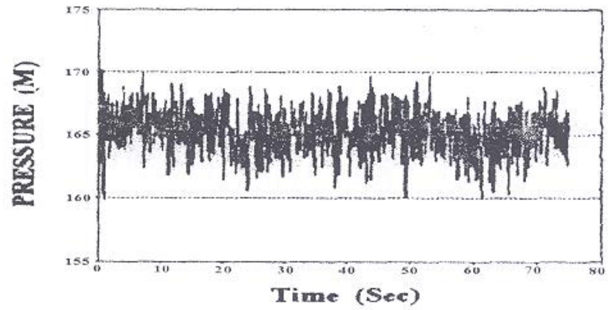
6. VELOCITYMEASUREMENT AT INFLOW AND OUTFLOWS SECTIONS

The velocity of inflow and outflow sections are measured by very thin "moline" on cross sections by defining three axes dividing each section into six equal part as shown in Figure 8. At inflow section which is bigger, the measurements are proceeded on 16 nodes on each axis. The number of measuring nodes on each axis of the outflow sections are 10.

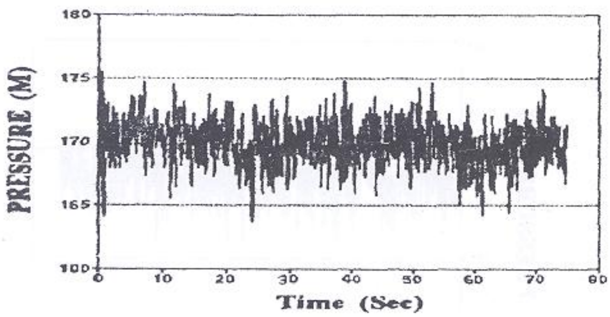
Figure 18 shows the velocity contours



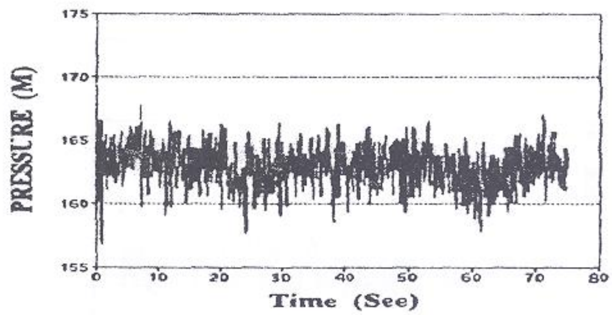
Piz. 1



Piz. 3



Piz. 4



Piz. 6

PIZ No.	P max	P min	P avg	STD	VAR
1	167.72	156.41	162.24	1.54	2.36
3	170.14	159.84	165.27	1.57	2.46
4	175.54	163.67	169.92	1.61	2.61
6	167.81	156.77	162.91	1.45	2.11

**For Pizometer Location See Drawing. No.*

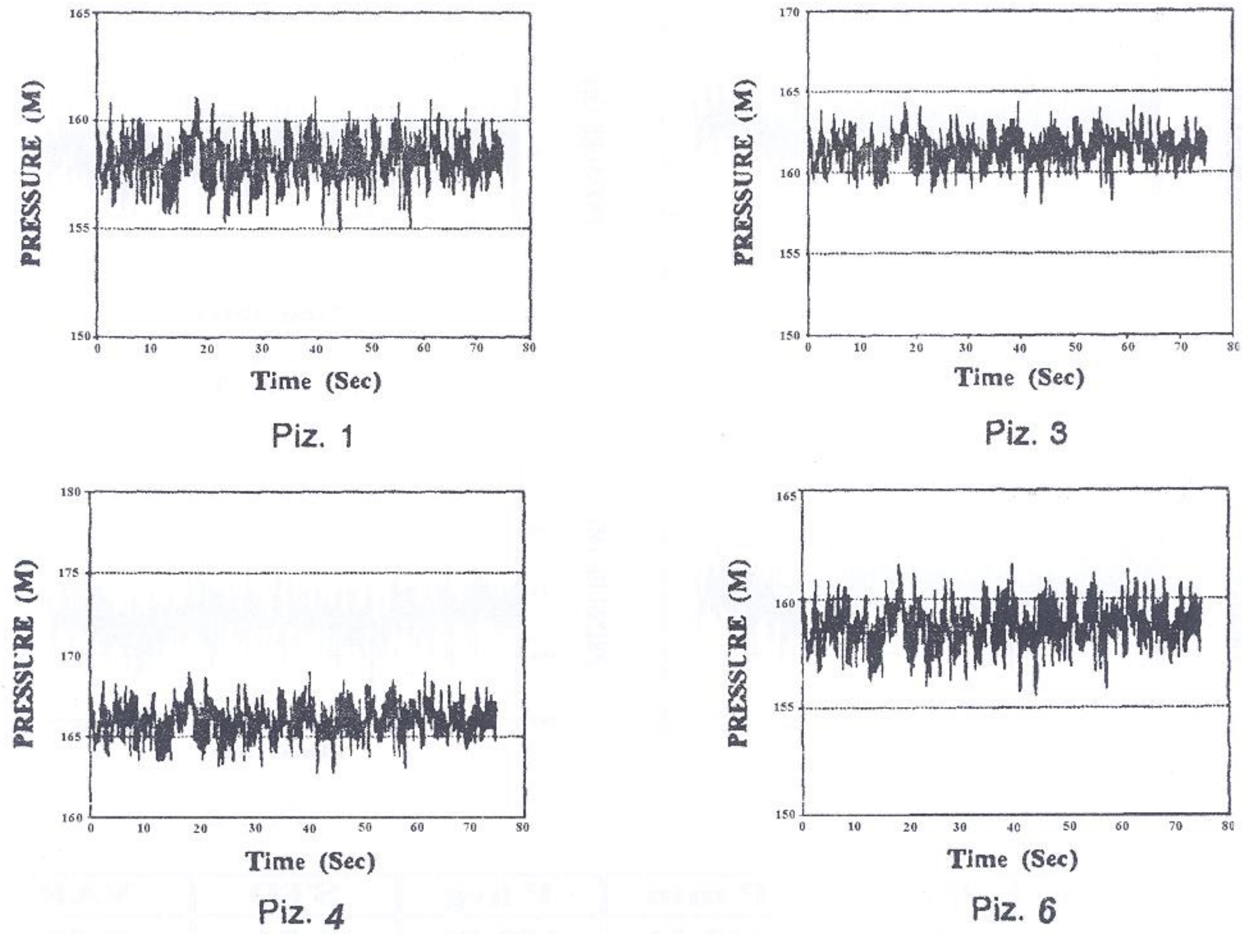
left branch:3/4 open ***right branch:open***

Q(L)=260 cms ***Q(R)=342 cms***

Figure 10. Dynamic pressure at Section 3 stiffener (1) left branch: 3/4 openright branch: open Q(L) = 260cms Q(R) = 342 cms.

measured at three inflow and outflows sections.The measured values of velocity on axis B on right section shows transfer of maximum to the top-left of cross section. However at the other cases a roughly symmetric condition is observed. The stated disturbance can mainly bedue to non-symmetric shape of branch which affects on stream lines. More disturbances can be observed on contour lines of left outflow section which shows non-symmetric conditions of velocity through cross section.

Despite of slightly different velocity distribution on right section and left, it can still be concluded that the degree of turbulency



PIZ No.	P max	P min	P avg	STD	VAR
1	161.13	154.82	158.10	0.98	0.96
3	164.38	158.04	161.38	0.94	0.89
4	168.97	162.76	165.96	0.99	0.98
6	161.56	155.59	158.72	0.93	0.86

**For Pizometer Location See Drawing. No. 8-b*

Figure 11. Dynamic pressure at Section 3 stiffener (1) left branch: 3/4 openright branch: open Q(L) = 260cms Q(R) = 342 cms.

through the Y-branch is low, and acceptable. Although, there is not any certain criterion for accepting velicity distribution through bronches, however, the velocity contours present that there is not any sever disturbad flow conditions across both branches.

7. CONCLUSIONS

In this research study, the effect of sickle rib geometry of the head loss coefficient of non-symmetric wye is achieved and mainly has concluded that the effect of sickle rib geometry

TABLE 1. Hydraulic Information of Branches (with Stiffener 1).

TEST NO.	RIGHT BRANCH	LEFT BRANCH	$Qr(m^3/s)$	$Ql(m^3/s)$	$Qm(m^3/s)$	Vr(m/s)	Vl(m/s)	Vm(m/s)
1	F.OPEN	F.CLOSE	11.8	0	11.8	3.39	0	1.45
2	F.OPEN	1/4OPEN	107.13	22.34	129.47	3.28	0.68	1.69
3	F.OPEN	1/2OPEN	107.13	51.85	158.98	3.28	1.59	2.08
4	F.OPEN	3/4OPEN	109.44	83.24	192.64	3.35	2.55	2.52
5	F.OPEN	F.OPEN	72.00	72.00	144.00	2.20	2.20	1.88
6	3/4OPEN	F.OPEN	82.21	112.88	195.09	2.52	3.45	2.55
7	1/2OPEN	F.OPEN	47.58	111.72	159.30	1.46	3.42	2.08
8	1/4OPEN	F.OPEN	22.34	111.72	134.06	0.68	3.42	1.75
9	F.CLOSE	F.OPEN	0	115.68	115.68	0	3.54	1.51

av.: average vale

TABLE 2. Calculation of Head Loss Coefficients (with Stiffener 1).

TEST NO.	Vl/Vm	RICHT $(P/•)_r$	LEFT $(P/•)_l$	MAIN $(P/•)_m$	Hm	Hl	Hm	• Hm-r	• Hm-l		
1	0	6.20	6.67	5.89	7.307	7.304	7.136	.0171	.003	1.6	0.028
2	0.4	6.228	6.741	6.129	7.428	7.402	7.337	.091	.026	0.62	0.180
3	0.76	6.63	6.617	6.210	7.478	7.383	7.418	.060	.095	0.27	0.430
4	1.01	6.304	6.498	6.312	7.622	7.466	7.544	.078	.156	0.24	0.480
5	1.17	6.298	6.494	6.545	7.472	7.378	7.452	.020	.094	0.11	0.520
6	1.35	6.294	6.070	6.632	7.619	7.314	7.616	.003	.305	0.01	0.920
7	1.64	6.267	6.026	6.714	7.482	7.259	7.483	-.001	.223	-0.05	1.010
8	1.95	6.302	6.046	6.799	7.452	7.279	7.483	-.031	.173	-0.02	1.110
9	2.34	6.266	5.918	6.757	7.376	7.194	7.417	-.041	.182	-0.35	1.570

TABLE 3. Hydraulic Information of Branches (with Stiffener 2).

TEST NO.	RIGHT BRANCH	LEFT BRANCH	$Qr(m^3/s)$	$Ql(m^3/s)$	$Qm(m^3/s)$	Vr(m/s)	Vl(m/s)	Vm(m/s)
1	F.OPEN	F.CLOSE	75.13	0	75.13	2.3	0	0.98
2	F.OPEN	1/4OPEN	107.1	20.44	127.54	3.28	0.63	1.67
3	F.OPEN	1/2OPEN	107.1	50.99	158.09	3.28	1.56	2.07
4	F.OPEN	3/4OPEN	109.42	85.32	194.74	3.35	2.61	2.55
5	F.OPEN	F.OPEN	72.00	72.00	144.00	2.20	2.20	1.88
6	3/4OPEN	F.OPEN	85.32	111.72	197.04	2.61	3.42	2.58
7	1/2OPEN	F.OPEN	49.27	110.57	159.84	1.51	3.38	2.09
8	1/4OPEN	F.OPEN	18.61	110.57	129.18	0.57	3.38	1.69
9	F.CLOSE	F.OPEN	0	74.56	74.56	0	2.28	0.98

TABLE 4. Calculation of Head Loss Coefficients (with Stiffener 2).

TEST NO.	Vl/Vm	RICHT $(P/\bullet)_r$	LEFT $(P/\bullet)_l$	MAIN $(P/\bullet)_m$	Hm	Hl	Hm	• Hm-r	• Hm-l		
1	0	6.207	6.612	6.246	7.25	7.248	7.176	.074	.001	1.52	0.027
2	0.38	6.285	6.738	6.131	7.421	7.395	7.339	.082	0.25	0.58	0.180
3	0.75	6.265	6.62	6.217	7.477	7.381	7.425	.052	.096	0.24	0.440
4	1.02	65.308	6.493	6.338	7.633	7.477	7.570	.063	.156	0.19	0.470
5	1.17	6.297	6.497	6.550	7.471	7.381	7.456	.014	.090	0.80	0.500
6	1.33	6.291	6.093	6.616	7.624	7.326	7.622	.001	.298	0.01	0.880
7	1.62	6.269	6.053	6.712	7.486	7.272	7.488	-.002	.214	-0.01	0.960
8	2.00	6.305	6.074	6.791	7.445	7.293	7.468	-.023	.152	-0.16	1.040
9	2.33	6.268	6.337	6.666	7.311	7.239	7.325	-.015	.072	-0.30	1.460

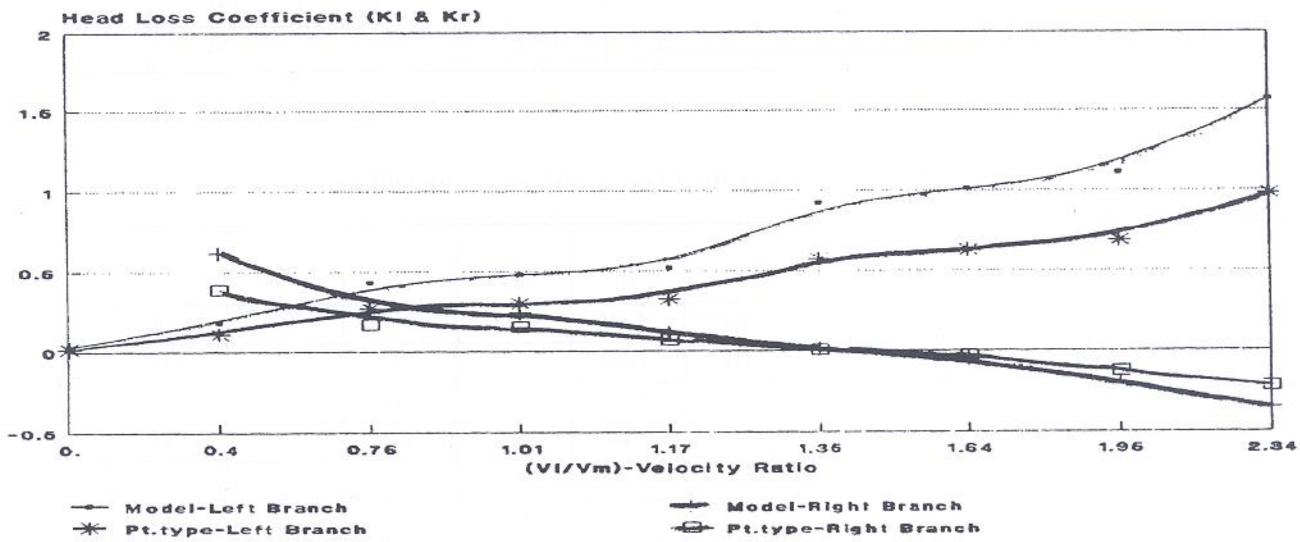


Figure 12. Variation of head loss coefficients.

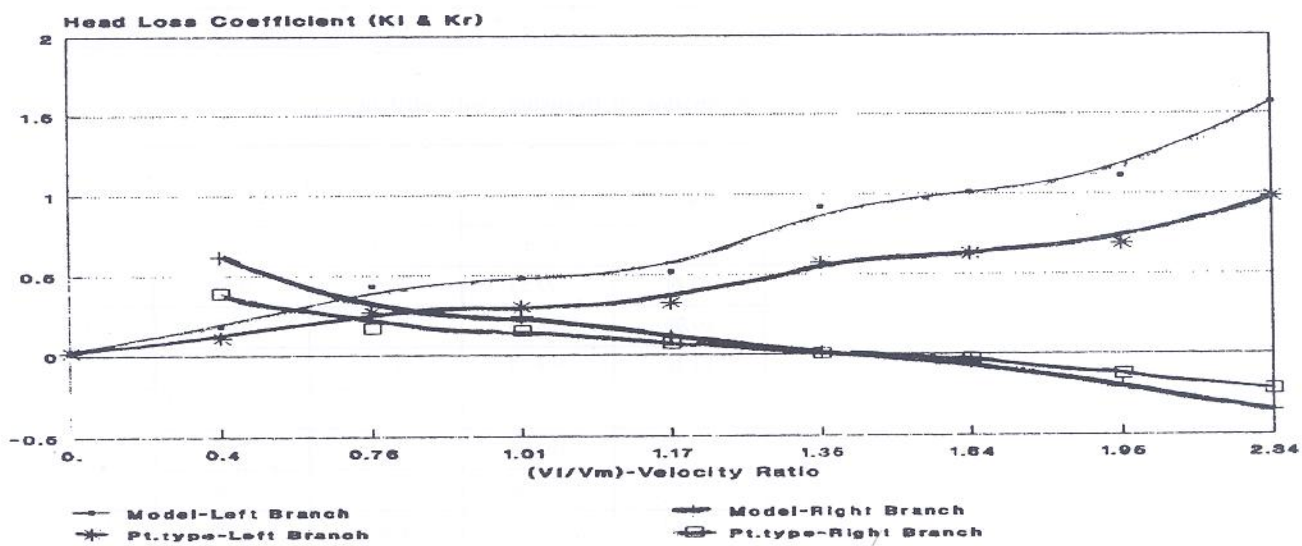


Figure 13. Variation of head loss coefficients.

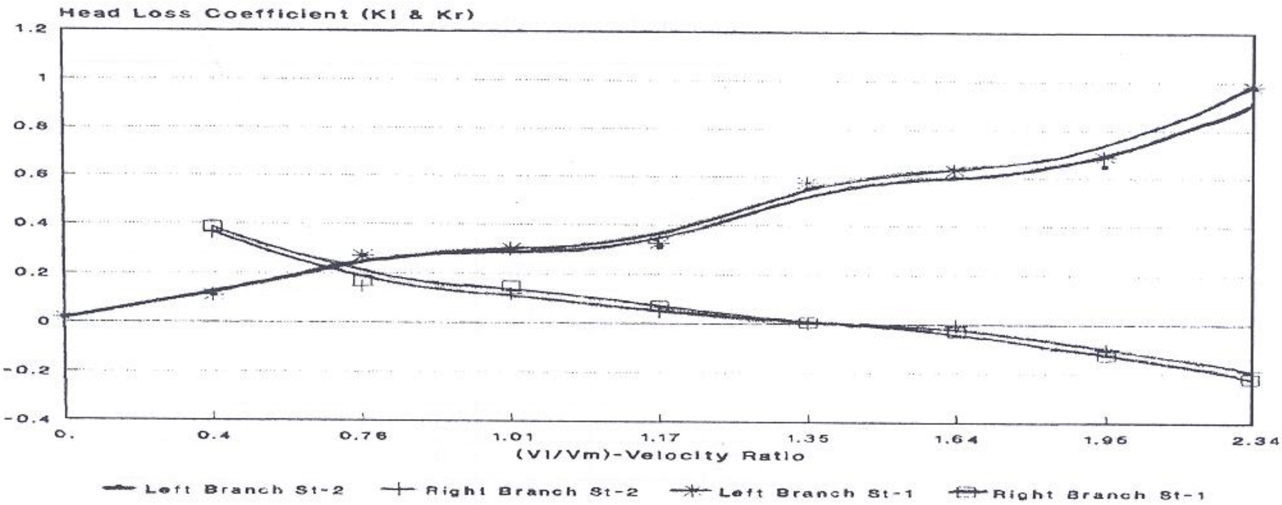


Figure 14. Variation of head loss coefficients.

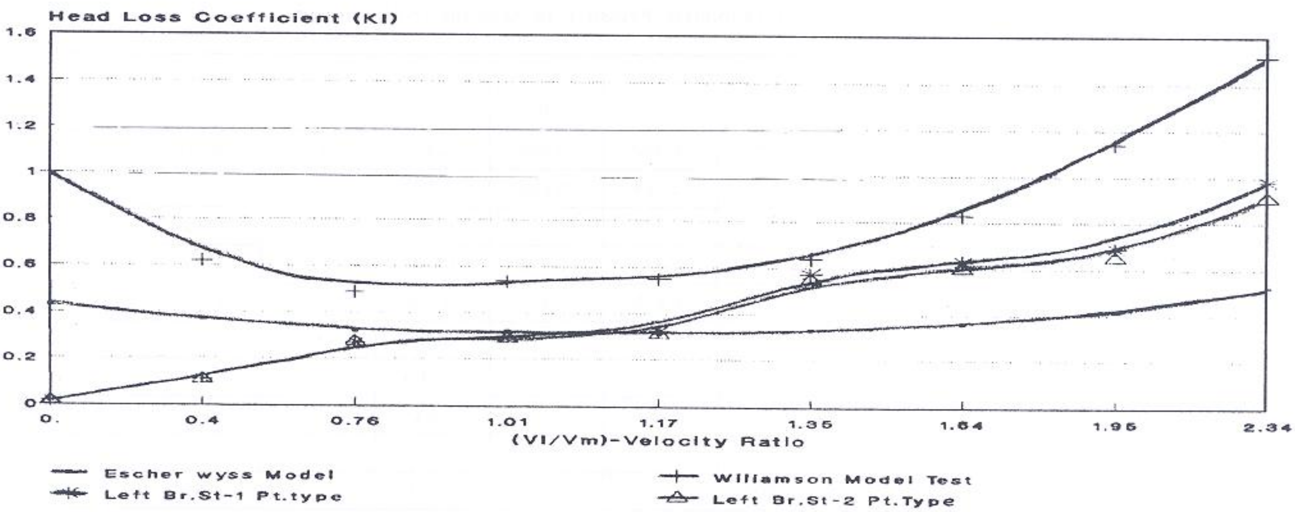


Figure 15. The comparison of left branch results.

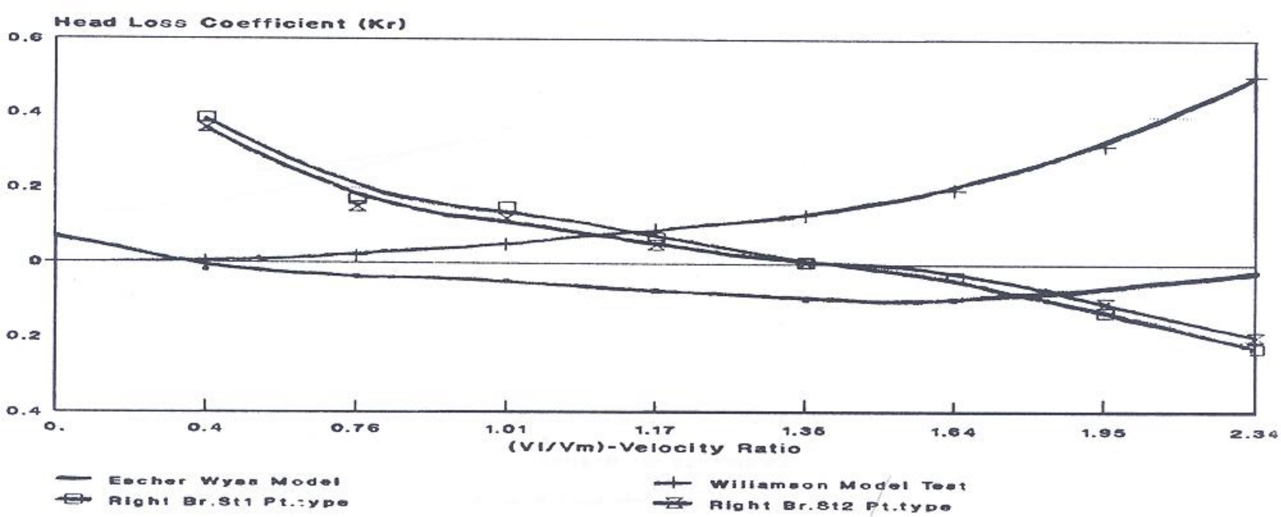


Figure 16. The comparison of right branch results.

TABLE 5. Average Piezometric Pressure in Sections (Stiffener 1).

PLES. NO.	SEC. 1	SEC. 2	SEC. 3	SEC. 4	SEC. 5	SEC. 6	SEC. 7	SEC. 8	SEC. 9
1	6.356	6.364	6.261	6.626	6.349	6.359	6.492	6.405	6.411
2	6.250	6.257	6.154	6.550	6.281	6.293	6.372	6.342	6.356
3	6.399	6.408	6.144	6.532	6.384	6.387	6.348	6.445	6.459
4	6.559	6.575	6.134	6.449	6.473	6.489	6.461	6.534	6.555
5	6.462	6.468	6.202	6.440	6.425	6.422	6.384	6.478	6.492
6			6.316	6.465			6.508		
7			6.499	6.590			6.590		
8			6.506	6.808			6.676		
9			6.380	6.802			6.722		
10				6.786			6.718		

SEC.: SECTION

TABLE 6. Average Piezometric Pressure in Sections (Stiffener 2).

PLES. NO.	SEC. 1	SEC. 2	SEC. 3	SEC. 4	SEC. 5	SEC. 6	SEC. 7	SEC. 8	SEC. 9
1	6.356	6.364	6.261	6.646	6.352	6.363	6.512	6.410	6.416
2	6.250	6.257	6.154	6.570	6.284	6.296	6.392	6.347	6.361
3	6.399	6.408	6.144	6.552	6.387	6.391	6.368	6.450	6.464
4	6.559	6.575	6.134	6.469	6.476	6.493	6.481	6.539	6.560
5	6.462	6.468	6.202	6.460	6.428	6.425	6.404	6.482	6.497
6			6.316	6.485			6.528		
7			6.499	6.609			6.560		
8			6.506	6.827			6.696		
9			6.380	6.821			6.742		
10				6.806			6.738		

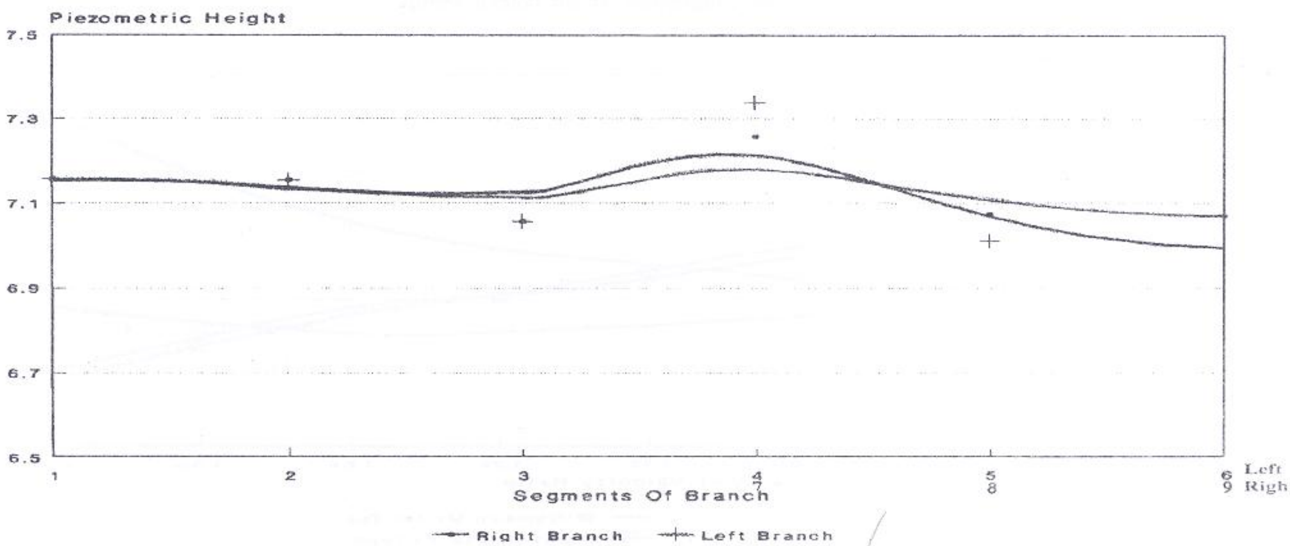


Figure 17. Right and Left piezometer lines.

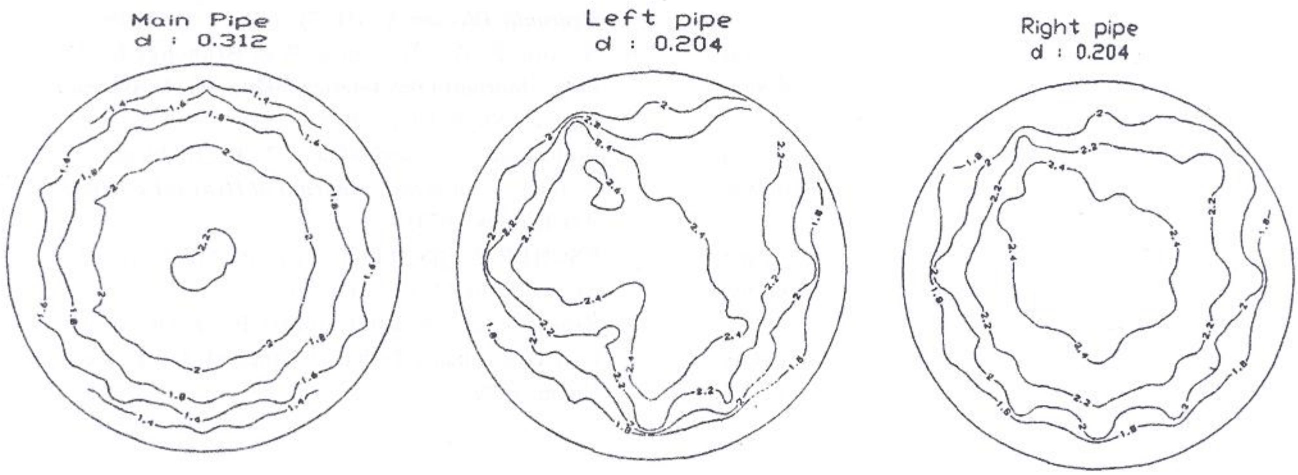


Figure 18. Velocity contours at intake and outlet.

upon usual choices is negligible. The coefficient of head loss of branches are affected by the variation of velocity ratio defined as R = V1/Vm (inflow velocity divided by average outflow velocity). In this case study, the coefficient of head loss in left branch while R> 0.5 (which is most probable) is more than for right branch.

According to the wye geometry the flow in right branch is tending to be more than the left one. For the wyes composed of cones the optimized flow rate is conformed with cone angles of 10° to 15°.

The obtained head loss coefficients are less than the values carried out through Williamson et al which are based on simple wyes without cones. This is most probable due to the transitions along branches.

The high pressure values in section 4 and 7 which is due to higher deviation angle, recommends to amend these deviation angle to reduce the needed thickness of steel liner.

The results prove that, changing in the shape of sickle rib geometry not significantly affects on pressure distribution of the steel liner.

No flow separation and cavitation observed at any location upon stated model conditions. The symmetry velocity distribution at inflow section and left outflow sectiovs reveals an acceptable wye geometry.

8. NOMENCLATURE

Q_r = Right Out Flow
Q_ℓ = Left Out Flow
Q_m = Main In Flow
V_r = Right Average Velocity
V_ℓ = Left Average Velocity
V_m = Main Average Velocity
$(\frac{\rho}{\gamma})_r$ = Head Pressure in Right Branch
$(\frac{\rho}{\gamma})_\ell$ = Head Pressure in Left Branch
$(\frac{\rho}{\gamma})_m$ = Head Pressure in Main
H_m = Energy in Main
H_r = Energy in Right Branch
H_ℓ = Energy in Left Branch
ΔH_{m-r} = H_m - H_r
$\Delta H_{m-\ell}$ = H_m - H_ℓ
K_ℓ = Head loss Coefficient in Left Branch

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