CURRENT–METER METHOD and PROFILE EXPLORATION at BRISAY POWER PLANT

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1. Introduction

Hydro–Québec's Brisay power plant was commissioned in 1993 and includes two units of 225 MW each under a variable head of 33 to 41 meters and a nominal discharge of 566 m^3/s. The turbines are of the Kaplan type and supplied by GE Canada. The bid called for efficiency tests on one unit by two methods, the current–meter and the acoustic.

The efficiency tests were done in 1994 using both methods simultaneously. Figure 1 presents a cross section of the installation showing the water intake, the waterway and the turbine installation from the spiral case entrance where the current–meter frame was installed to the turbine outlet. The current–meter metering section includes a frame supporting 104 current–meters in an 11 meter diameter steel lined penstock.

The main goal of this article is to study the importance of the profile exploration by means of current–meters and how it is affecting the calculated discharge. Since Brisay is a special case where 104 velocities were measured, it will help to draw conclusions regarding the code recommendations.

2. Description of the waterway and of the current–meter frame

The waterway includes a 500 meter long tunnel having a rectangular form and a round ceiling, see figure 1. The tunnel is 12.2 meters wide, 15.6 meters high, excavated through solid granite and has a surface roughness of about ± 0.3 meter. The tunnel is connected to an 11 meter diameter steel lined penstock through a variable geometry section, situated 45 meters upstream of the turbine scroll case entrance. The draft tube discharges directly into the river.

The current–meter frame was installed 24 meters upstream of the turbine vertical axis. The frame was preceded by a 36 meter straight portion ($\simeq$ 3.3 Ø) and followed by a ten meter section ($\simeq$ 0.95 Ø) before the scroll case entrance. Figure 2 is a picture showing the current–meter frame composed of 16 arms, of which only two are complete cross diameters, and whose total frontal area is less than 2 %.

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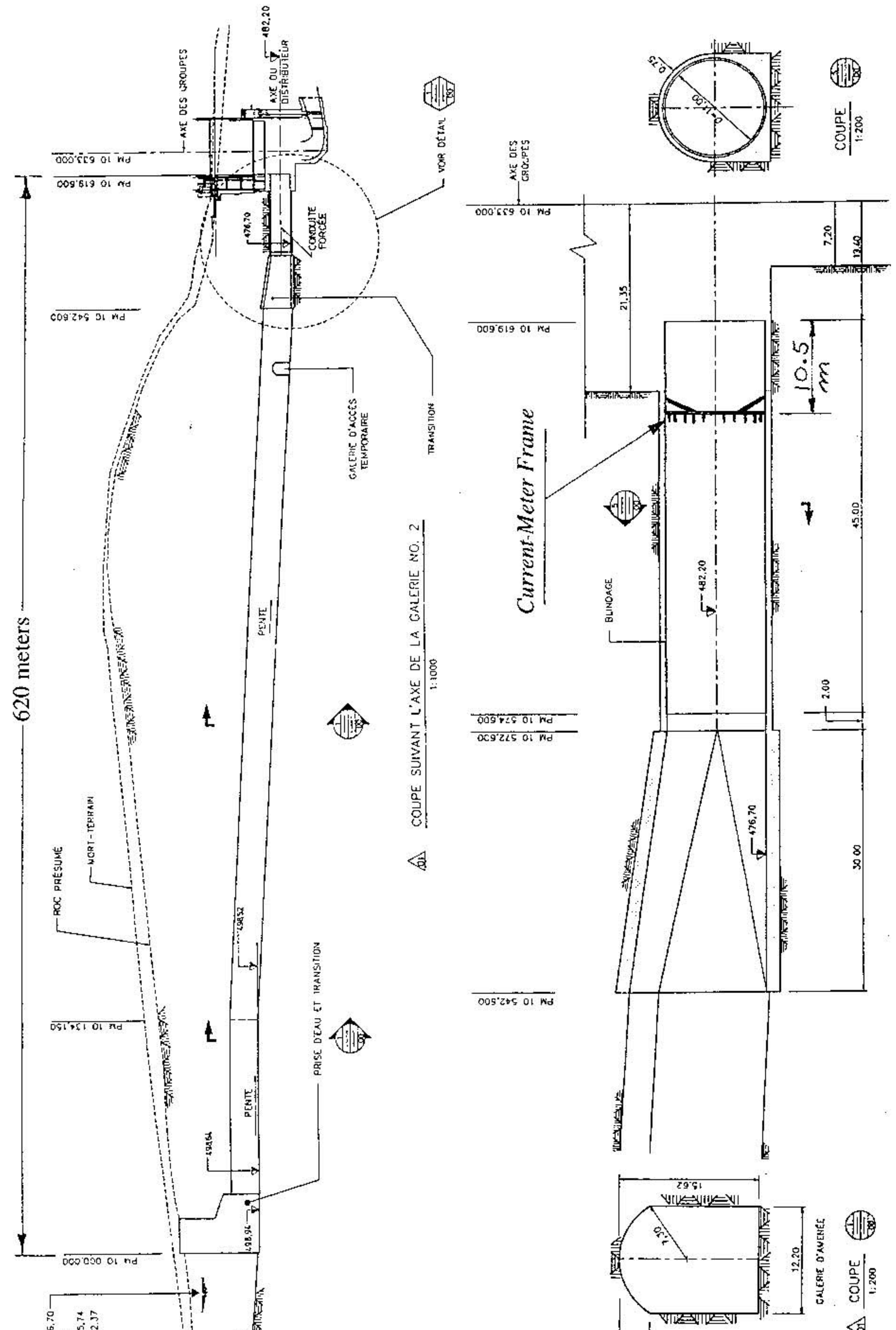

Figure 1: Brisay Installation

The current–meters were placed on 9 concentric rings plus 4 current–meters near the centre. On the first ring near the liner, 16 small current–meters of 50 mm propeller were used to measure the velocities at 81 mm from the wall. The second ring from the wall was equipped with 8 small current–meters and 8 normal ones of 150 mm propeller. The 7 subsequent rings had normal size current–meters. Except for the first ring, all the other 8 rings were of equal area. All the current–meters were supported by special oblique holders, the same that were used for their calibration in Berne, in 28 points from zero to 8 meters per second. During the testing, all the current–meters functioned correctly and the inspection after the tests revealed no faults.

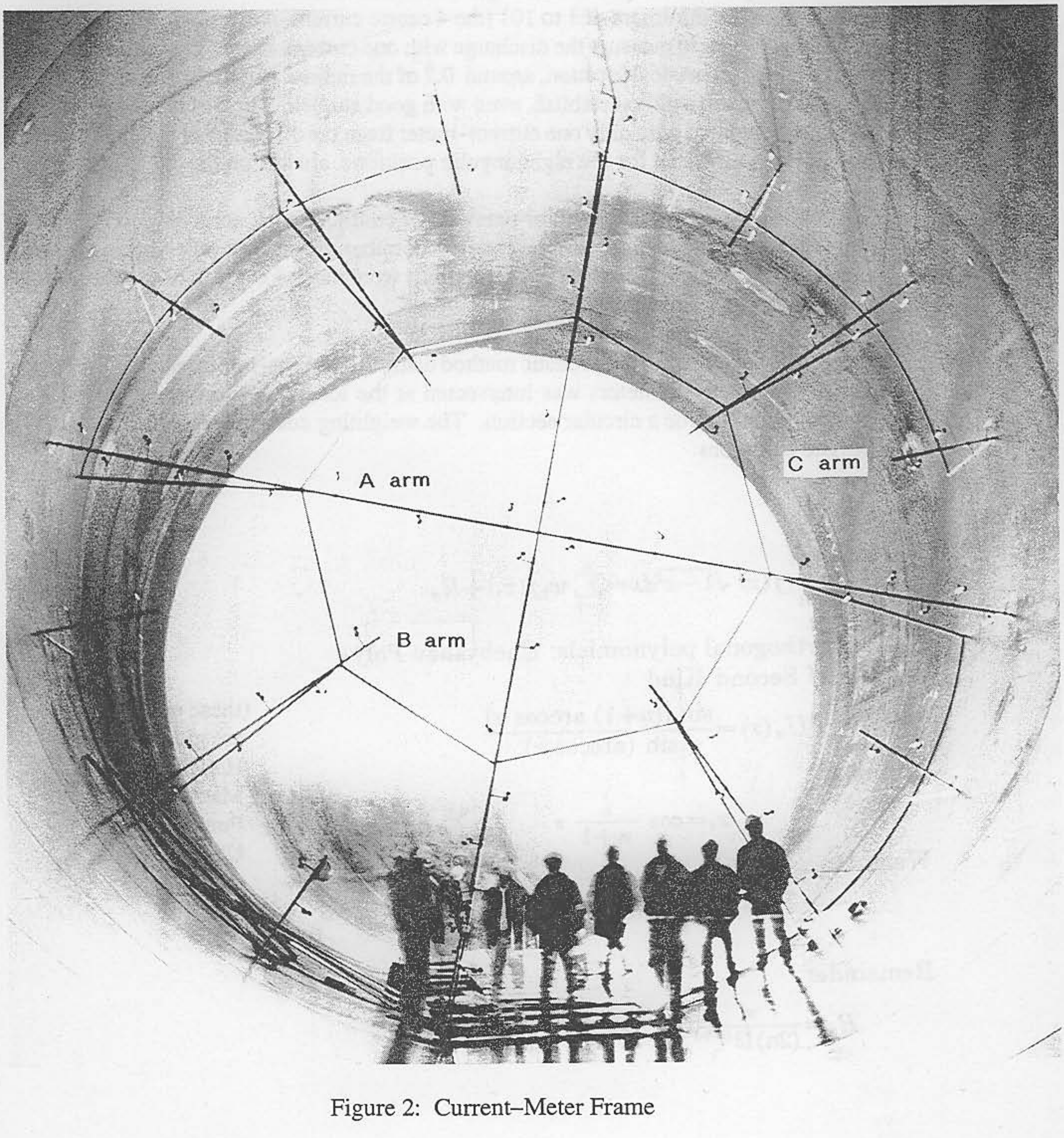

Figure 2: Current–Meter Frame

3. Logistics of the work and computation of the results

As stated in the introduction, the goal of the present study is to evaluate the uncertainty of the discharge measurement from a limited amount of current–meters. We believe that the Brisay measurements are of great interest due to the fact that the waterway does not meet the code recommendations, and in addition, many more current–meters were used than the code's required number and all current–meters performed faultlessly.

To establish the uncertainty of the computed discharge, we use a limited number of the current–meter measured velocities, from the minimum of 1 to 101 (the 4 centre current–meters will be considered as one). Naturally, if one wants to measure the discharge with one current–meter, this current–meter would be placed at the best theoretical location, around 0.7 of the radius. But the angle of this measuring point might be more difficult to establish, even with good studies. The discharge difference between the discharge computed with only one current–meter from the discharge of reference (with 101 current–meters) was calculated for the eight angular positions, always on the 0.7 R_0 ring.

The discharge difference was also evaluated for many other combinations, according to different hypotheses. Some of these combinations are the code's recommendations but others are not. The different combinations are given in table 1. The calculations were made for seven discharges from 351 to 562 m^3/s to ensure better results.

The study was also made according to the acoustic method using the current–meter results. The flow profile determined by the current–meters was intersected at the locations recommended for the acoustic Gauss–Jacobi method for a circular section. The weighting coefficients were calculated using the appropriate equations:

$$\int_{-1}^{+1} f(x)\sqrt{1-x^2}dx=\sum_{i=1}^{n} w_i f(x_i)+R_n$$

Related orthogonal polynomials: Chebyshev Polynomials of Second Kind

$$U_n(x)=\frac{\sin[(n+1)\arccos x]}{\sin(\arccos x)}$$

Abscissas:

$$x_i=\cos\frac{i}{n+1}\pi$$

Weights:

$$w_i=\frac{\pi}{n+1}\sin^2\frac{i}{n+1}\pi$$

Remainder:

$$R_n=\frac{\pi}{(2n)!2^{2n+1}}f^{(2n)}(\xi)\qquad(-1<\xi<1)$$

(these equations are given in the Handbook of Mathematical Functions of US Dep. of Commerce, NBS)

Table 1: Combinations of number of points for exploration

Current–meters		Radius arms			Circular rings									Centre	Note
Installed	Calculated	Type A	Type B	Type C	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9		
104	101	4A	4B	8C	X	X	X	X	X	X	X	X	X	X	
88	85	4A	4B	4C	X	X	X	X	X	X	X	X	X	X	
80	77	4A	4B	8C	X	X	X	–	X	X	X	–	X	X	
72	69	4A	4B	–	X	X	X	X	X	X	X	X	X	X	
68	65	–	4B	4C	X	X	X	X	X	X	X	X	–	X	
56	53	4A	4B	8C	X	–	X	–	X	–	X	–	X	X	
50	47	4A	–	–	X	X	X	X	X	X	X	X	X	X	(1)
		–	4B	–	X	X	X	X	X	X	X	X	–	X	(2)
40	37	4A	–	–	X	X	X	X	X	X	X	X	X	X	
44	41	4A	4B	–	X	–	X	–	X	–	X	X	–	X	
36	33	–	4B	–	X	X	X	X	X	X	X	X	–	X	
		4A	4B	–	X	–	X		X	–	X	–	–	X	
		4A	–	–	X	–	X	X	X	X	X	X	X	X	
		4A	–	–	X	X	X	X	X	X	X	–	X	X	
32	29	4A	–	–	X	X	–	X	X	X	X	X	–	X	
		4A	–	–	X	–	X	X	X	X	–	X	X	X	
		–	4B	–	X	–	X	X	X	X	X	X	–	X	
		–	4B	–	X	X	–	X	X	X	X	X	–	X	
28	25	4A	–	–	X	–	X	X	–	X	X	–	X	X	
		4A	–	–	X	X	–	X	X	–	X	X	–	X	
		–	4B	–	X	–	X	X		X	X	X	–	X	
		4A	–	–	X	X	X	X	–	X	–	X	–	X	
24	21	4A	–	–	X	–	X	–	X	–	X	X	–	X	
		–	4B	–	X	–	X	–	X	–	X	X	–	X	
20	17	4A	–	–	X	–	X	–	X	–	X	–	–	X	
		–	4B	–	X	–	X	–	X	–	X	–	–	X	
16	13	4A	–	–	X	–	–	X	–	–	X	–	–	X	
		–	4B	–	X	–	–	X	–	–	X	–	–	X	
		4A	–	–	–	X	–	–	X	–	–	X	–	X	
		–	4B	–	–	X	–	–	X	–	–	X	–	X	
31	28	3A	–	–	X	X	X	X	X	X	X	X	X	X	(3)
29	25	–	3B	–	X	X	X	X	X	X	X	X	–	X	(3)
30	26	1A	2B	–	X	X	X	X	X	X	X	X	X	X	(4)
21	19	2A	–	–	X	X	X	X	X	X	X	X	X	X	
19	17	–	2B	–	X	X	X	X	X	X	X	X	–	X	
10	10	1A	–	–	X	X	X	X	X	X	X	X	X	X	(5)
9	9	–	1B	–	X	X	X	X	X	X	X	X	–	X	(5)
1 to 8	1 to 8	–	–	–	–		–	–	X		–	–	–		(6)

(1) : Plus 10 current–meters on 4 type B arms.
(2) : Plus 14 current-meters on 4 type B arms.
(3) : Corresponding of loss of one type A or B arm ("T" installation).
(4) : Two type B arms opposed to one type A arm ("Y" installation).
(5) : One type A or B arm moving around the centre.
(6) : Combination of one to eight points on the ring R_5

4. The results

4.1 Exploration of the circular section by concentric rings

The results are presented in figure 3 for the exploration by a given number of points in the circular section. All the calculations were made according to ISO 3354–1975, paragraph 9: "Determination of the discharge velocity by numerical integration of the velocity area". The flow profile coefficient "m" due to the wall roughness was calculated from measured velocities and varied from 9.3 to 9.6, but assumed in certain cases where the number of current–meters was insufficient.

The variation of the calculated flow can be summarized as follow:

- With 13 points comprising 3 points on 4 arms, the calculated flow variation is $\simeq$ 2 %.
- With 17 points comprising 4 points on 4 arms, the calculated flow variation is $\simeq$ 0.3 %.
- With 29 points comprising 7 points on 4 arms, the calculated flow variation is $\simeq$ 0.3 %.
- With 33 points comprising 8 points on 4 arms, the calculated flow variation is $\simeq$ 0.2 %.
- With 33 points comprising 4 points on 8 arms, the calculated flow variation is $\simeq$ 0.1 %.
- With 37 points comprising 9 points on 4 arms, which is the minimum number of points recommended in the codes for an 11 meter diameter conduit, the calculated flow variation is $\simeq$ 0.2 %.
- With 41 points comprising 5 points on 8 arms, the calculated flow variation is $\simeq$ 0.1 %.
- With more than 65 points, either 8, 12 or 16 arms, the calculated flow variation is $\simeq$ 0.05 %.

Figure 4 shows different odd combinations, not code accepted, but in order to illustrate the kind of deviation, one can obtain by partial flow exploration. It appears clear that 17 points distributed on four arms, are enough to maintain the uncertainty to less than 0.5 %.

4.2 Exploration of the circular section by cords

This exploration of the flow profile was done on cords corresponding to the acoustic method using N paths. The results are reported in figure 5 for horizontal and vertical paths and also for angles of 45 and 135 degrees. The differences of flow are referenced to the flow calculated using the 101 current–meters, which agrees within 0.01 % with the flow of 18 paths. All calculations were made wall to wall, so no protrusion effect is present. The main results are the following:

- A 3 path integration yields a flow difference of $\simeq$ 0.5 %.
- A 4 path integration yields a flow difference of $\simeq$ 0.25 %.
- A 5 and 6 path integration yields a flow difference of $\simeq$ 0.07 %.
- A 7 and more path integration yields a flow difference of $\simeq$ 0.03 % or less.
- Vertical path integration provides better results or less error.

5. Conclusions

The study done with the current–meter test results at Brisay power plant clearly indicates the following conclusions:

- The uncertainties mentioned in the code are too conservative and do not reflect a confidence limit of 95 %. For an 11 meter diameter conduit, the codes require a minimum of 37 points on four arms, associated with straight length requirements of 25 diameters upstream of the metering section. At Brisay, these conditions were not present and the uncertainty related to the exploration with 37 points is $\simeq$ 0.25 %.
- A better exploration is done by increasing the number of arms even for a rather small number of rings. For example with 41 points, better accuracy will be obtained by placing the current–meters on 6 or 8 arms than by placing them on 4 arms.
- A four cord integration, which corresponds to the standard acoustic disposition, gives a flow difference of $\simeq$ 0.25 %.
- A five (and more) cord integration permits to reduce the flow difference to $\simeq$ 0.1 %.
- The difference between the flow computed by cubic equations (numerical integration given in ISO code) and the flow computed by a completely different method, using coefficients determined by Chebyshev Polynomials of Second Kind, decreases to $\simeq$ 0.01 % for 18 cord integration. That confirms that both methods are very accurate and no margin should be applied for uncertainties resulting from the computation method.

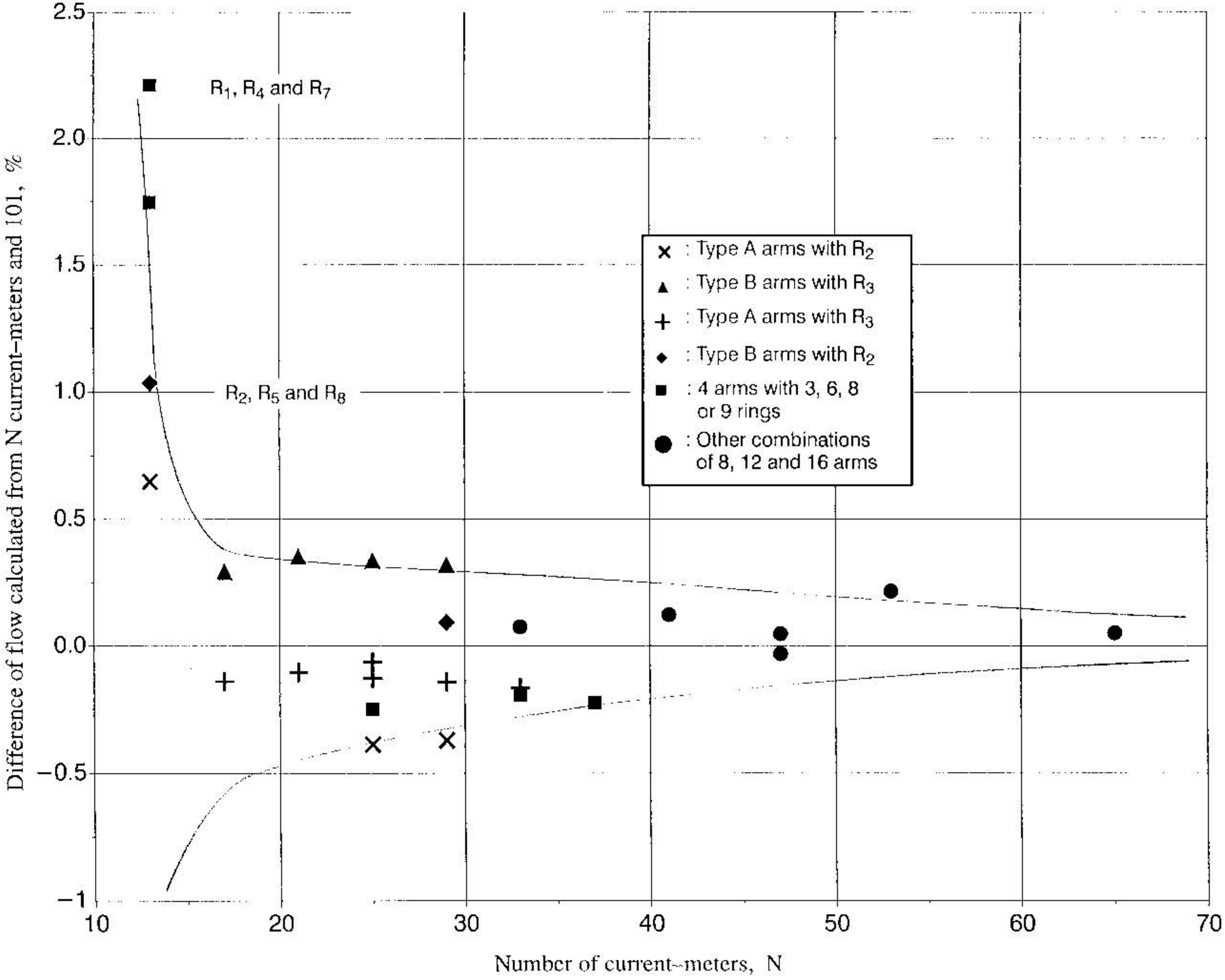

Figure 3: Variation of calculated flow according to different combinations recommended in the codes (CEI 41 and ISO 3354)

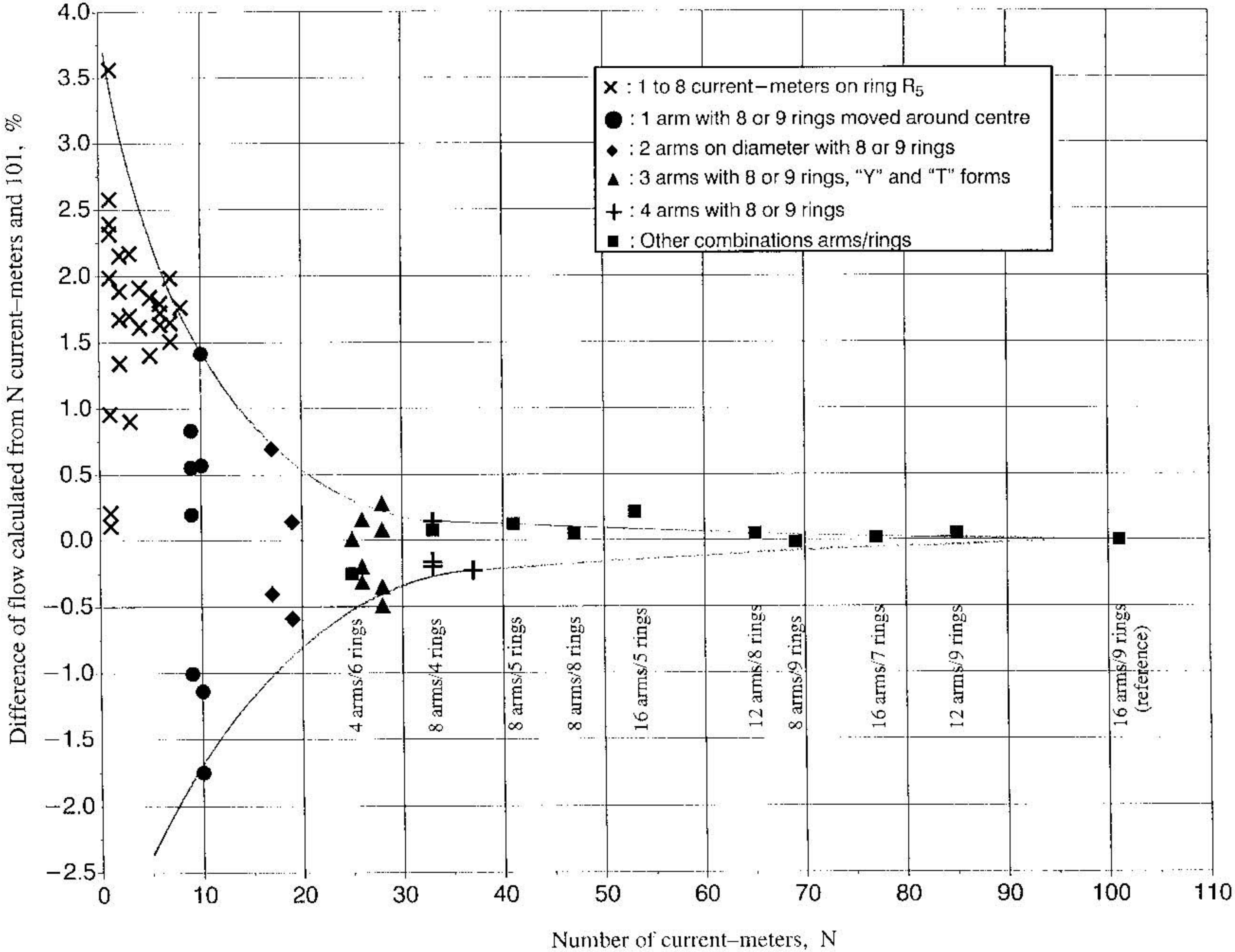

Figure 4: Variation of calculated flow for code recommended combinations and for odd combinations

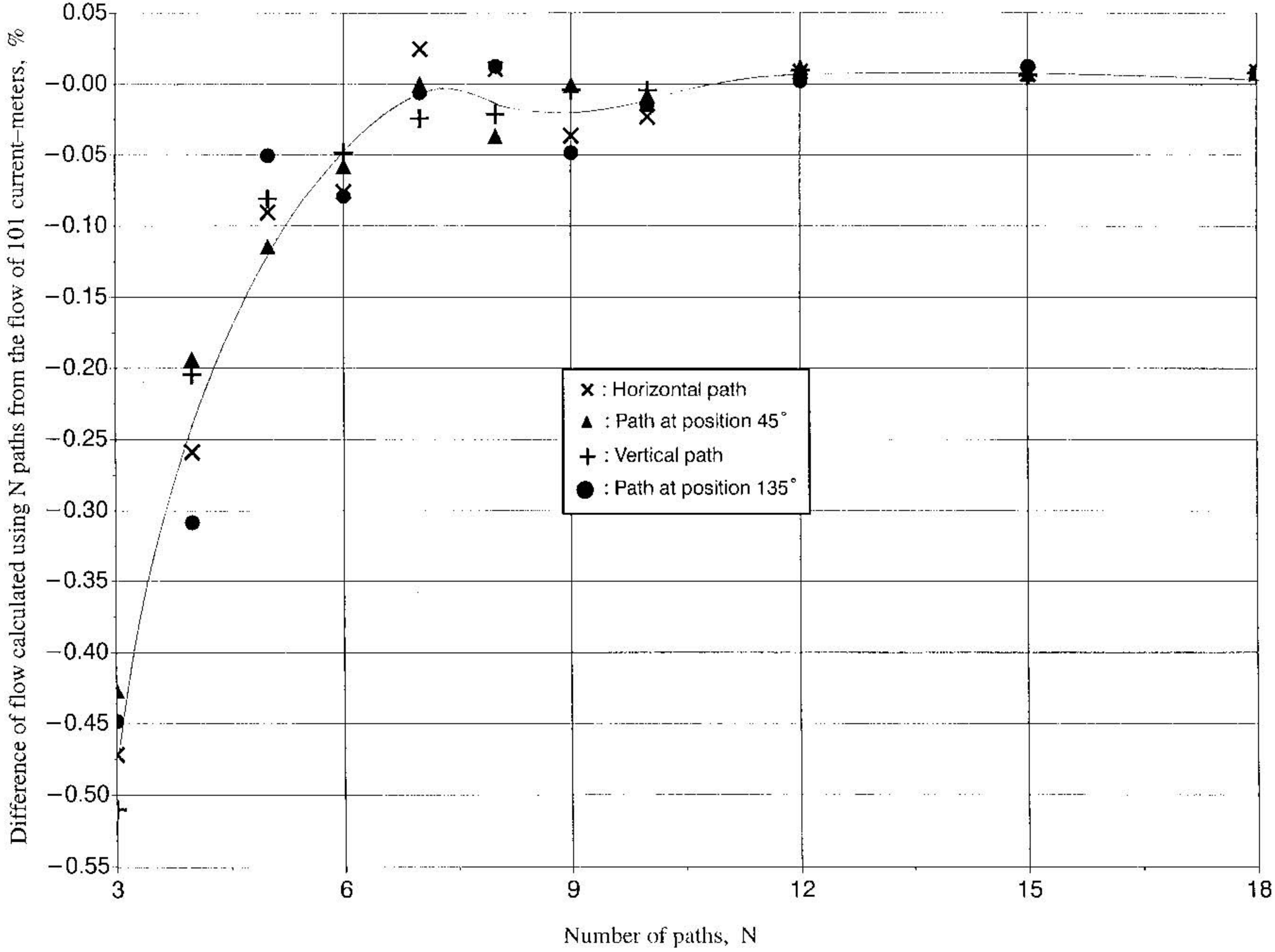

Figure 5: Calculated flow against number of points used for the exploration of paths