THE SHROUD OF TURIN: A TECHNICAL STUDY

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On the 21st of April 1988, the Shroud of Turin was examined and samples were taken for the dating of the relic by carbon 14. I had been invited by the Archdiocese of Turin to be present at this operation in company with Professor Testore, professor of Textile Technology at the Polytechnical School of Turin, and with Signor Giovanni Riggi, president of the Turin office of STURP. I was thus able to profit by this unique occasion to proceed to a technical examination of the celebrated relic.

It seems that the essentials have been given, notably by Vignon[1] who, in 1938, defined the cloth as a linen 3:1 herringbone twill weave.

The studies of ancient textiles undertaken by the Centre International d'Etude des Textiles Anciens (CIETA) since 1955 show that numerous details extremely interesting for future comparisons could be overlooked by a rapid and superficial study. Therefore, I present here my observations on the nature and construction of the fabric and discuss the technical comparisons that have been advanced.

The Document (Fig. 1)
Total dimensions: length 4.30 m x width 1.08 m.

There are two parts:
- The main piece, whereon lies the image, measuring 4.30 m x 1.08 m
- A lateral band, attached by a seam, measuring 3.80 x 0.08 m

The sidestrip (to retain the generally adopted appellation) has been sewn to the main piece without symmetrical correspondence. Facing the frontal image, the observer notices that the sidestrip is 14 cm shorter than the length of the Shroud, while above the dorsal image it lacks 35-36 cm. At the places where it is lacking, one sees the cloth which serves as a lining for the entire sheet. All the way around the "actual document" is found a rolled hem. It was not possible to determine whether this exists under the seam that joins the two parts.

A **selvage** was found along both lateral edges: at the outside of the main piece and at the outside of the sidestrip (S.I & S.II, Fig. 2). In spite of the presence of the two selvages, one cannot pronounce upon a "width of the cloth" because the cut between the main piece and the sidestrip precludes any statement that this is the whole of the original fabric.

THE TECHNIQUE (Fig. 2.A)

Description: A chevron (herringbone) twill weave with the chevrons oriented in the warp direction (vertical herringbone twill). The structure is a 3:1 twill with symmetrical points composed theoretically of:

41 threads in the straight series
39 threads in the return series, repeat: 80 threads and 4 passes.

This arrangement is based on the theory that the straight series of threads will form the points which are the axes of symmetry for the chevrons. The return series is made up of 2 fewer threads even though the branches of the chevron look equal. This explains why past observers who are not familiar with the theory consistently refer to a series of 40 threads.

Typical Types of Faults in Weaving: Without undertaking a long and systematic study, two types of faults are evident:

Type 1: The existence of some series that are too narrow (37 threads for example), and some that are too wide (45 threads). I have attributed these numbers to the straight series, and note that they comprise a difference of 4 threads. This relates exactly to the number of threads making up the basic unit of the 3:1 twill weave. This does not preclude the existence of other deviations which would theoretically have to follow the same criteria.[2]

Type 2: The existence of narrow rows where the depressed paths of the twill reverse for short distances (generally 5 threads, including the point threads which had been raised [Fig. 4]). One of these rows is situated exactly 45 cm. from the selvage of the main piece (Fig. 1. VII). It continues along the whole length of the cloth, and it is likely that this is also the case with other similar bands.[3]

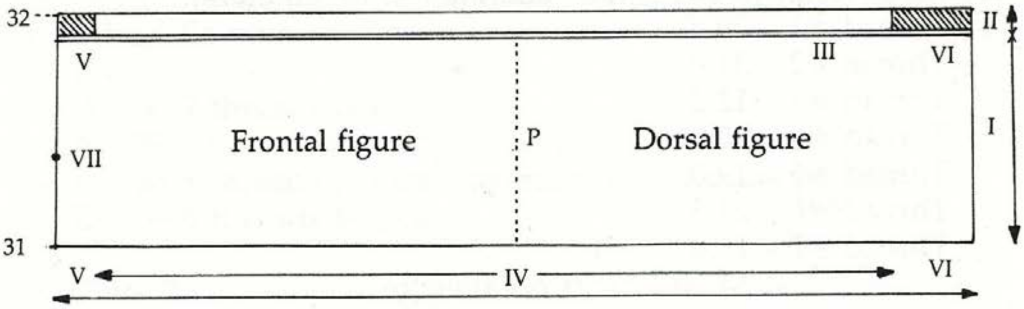
These two types of faults, which are easy to notice, are discussed below (see comments on the weaving techniques).

WARP

Fiber: Linen, single twist, "Z" direction, unbleached.

Regularity of the Spinning: Contrary to what some authors have written, the thread is not spun with great regularity. A simple observation shows that neighboring threads have an apparent diameter that varies by a factor of three. A quick measure of 7 threads,

Fig. 1: Scheme of the document.



I–Width of the main piece
ca. 101 cm

II–Width of the sidestrip
ca. 8 cm

III–Width of the seam
ca. 0.5 cm

IV–Length of the sidestrip
ca. 380 cm

V–Length of (small) uncovered space
ca. 14 cm

VI–Length of (large) uncovered space
ca. 36 cm

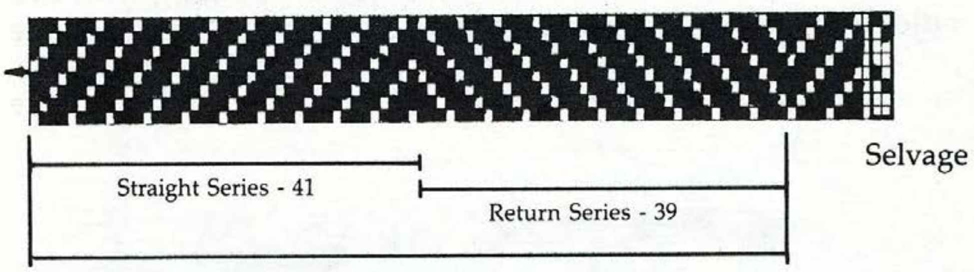
VII–Fault of the tying up, 45 cm from S1

S1–Selvage of main piece

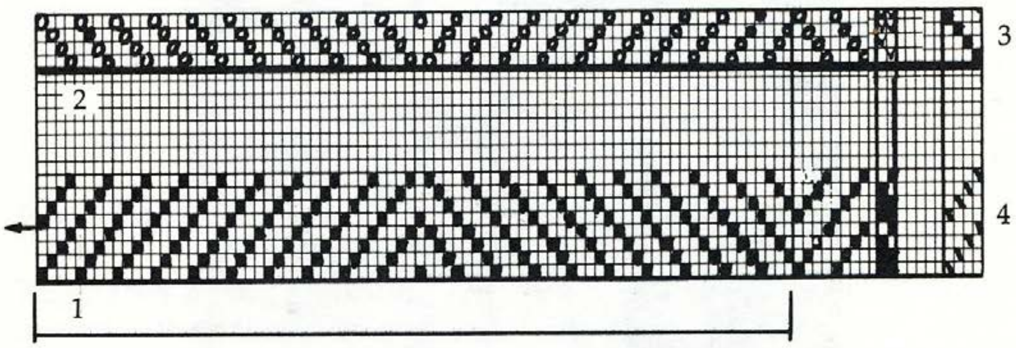
S2–Selvage of sidestrip

P–Partition line between the two images

Fig. 2: Technical diagram of the weave & selvage.



A–View of right side of fabric, warp float face (notice the selvage).



B–Execution on a loom with shafts and treadles (weft float face uppermost).

B-1–Fabric as seen on the loom.

B-2–Threading.

B-3–Tying of the treadles to the shafts.

B-4–Action of the weaver on the treadles.

made on the enlarged photo of Figure 3, gave the following measurements (relative sizes, not calibrated in millimeters):

Thread #1 — 20.5
Thread #2 — 31.0
Thread #3 — 12.2
Thread #4 — 22.3
Thread #5 — 19.0
Thread #6 — 23.3
Thread #7 — 18.8
147.0 / 7 = 21 on average.

Threads #2 and #3 diverge by about 50% from the average. This is altogether normal for a handspun thread and is encountered in all ancient textiles.

Twist: The "Z" direction is unusual. A long time ago, it was noted that the "S" direction, generally used for spinning linen, corresponds to the natural direction the fiber takes when it dries. It had been used since the first Egyptian dynasties and persisted in Egypt up to the XVth—XVIIth centuries.[4] However, some authors have observed that "yarns produced manually with two spindles, spun simultaneously with the right hand and the left hand, must have a twist in opposite directions".[5] The technique of spinning with two spindles was well known, not only in ancient Egypt but also in the Coptic period.[6] Furthermore, although quite rarely, linen threads with a "Z" twist have been mentioned at Palmyra and in the Judean desert.[7]

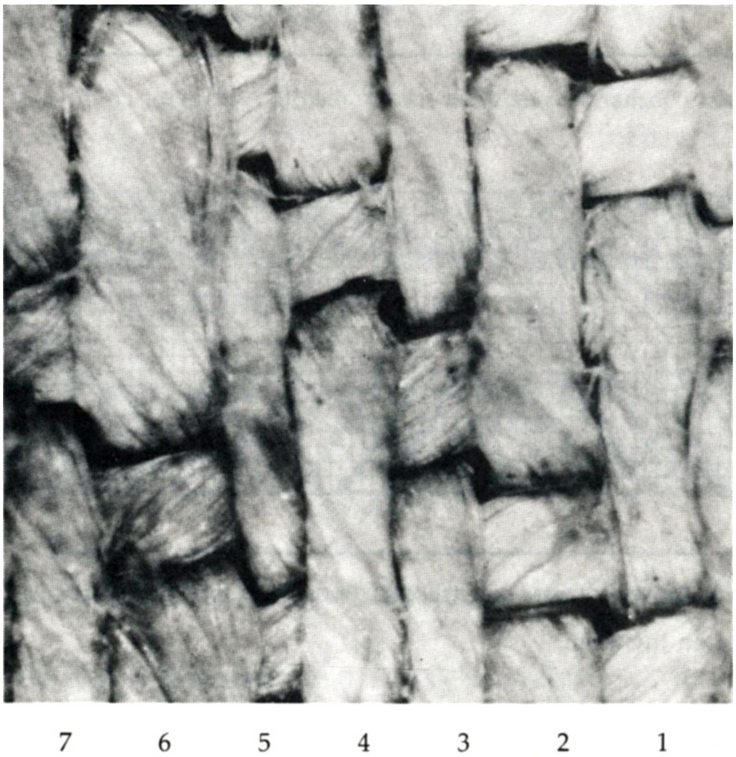


Fig. 3: Irregularity of the warp.

Thread Count: Some thread counts were taken at different places on the cloth, each measurement being done at a distance of 2.7 cm, with the following results:

Piece 1
A — 37.7 threads per cm
B — 37.4 threads per cm
C — 38.5 threads per cm average 38.3 threads per cm
D — 39.6 threads per cm

Piece 2
E — 38.1 threads per cm average 38.1 threads per cm.

Measurements from the photo illustrating the faults studied (Fig. 4) gave 201 threads in 5.35 cm or 37.6 threads per cm. One can therefore estimate the thread count of the warp to be approximately 38 threads per cm.

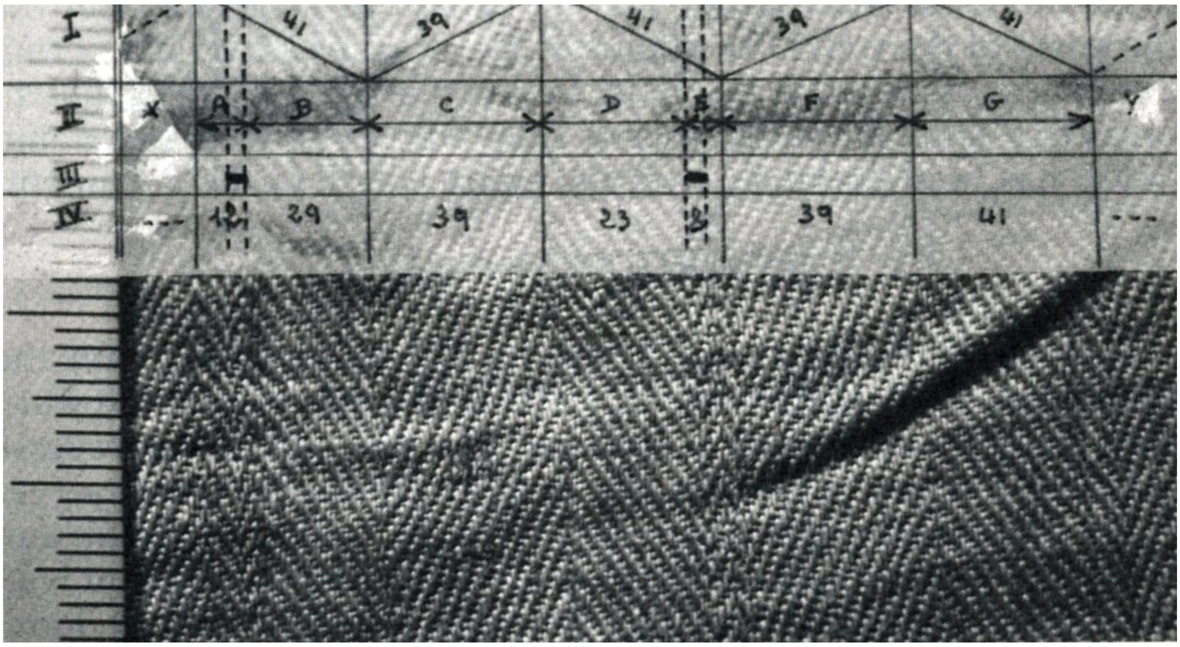


Fig. 4: Diagram of the two faults discussed.

WEFT

Fiber: Linen, single twist, "Z" direction, unbleached.

Regularity of the Spinning: The thread is thicker and seems more irregular than the warp.

Twist: It is identical to the warp threads; the same comments made above about the unusual twist also apply here.

Thread Count: Six counts were taken at different places on the cloth, each one over a distance of 2.7 cm and from both pieces of the document (main piece and sidestrip). They gave the following results:

Piece 1
F - 25.2 passes per cm }
G - 25.2 passes per cm } average of 25.4 passes per cm
H - 25.9 passes per cm }

Piece 2
I - 27.8 passes per cm }
J - 26.7 passes per cm } average of 26.2 passes per cm
K - 24.1 passes per cm }

average of 25.8 passes per cm

These results demonstrated a slight difference between the thread count of the weft of the main piece of the cloth and that of the sidestrip. This fact is not very significant considering how few measurements were taken and the variations ascertained in the thickness of the weft. The photos of the reverse side do not permit a sufficient appraisal to be made. I think that a definitive judgment cannot be made until the reverse side, where the weft face dominates, has been examined over the entire length of the document.

CONSTRUCTION (Fig. 2.B)

The chevron is executed in the traditional manner, with the chevron or herringbone twill oriented in the direction of the warp with symmetrical points of change. The diagonal series reverse their direction on both sides of a single warp thread which serves as the axis of symmetry. The usage of the 3:1 twill for the basic unit of the chevrons gives the cloth two different faces: a dominant weft float face, which is seen by the weaver on the loom, and a dominant warp float face which is found underneath the weaving. It is on this face that the image is located.

This weaving method, called "face down," requires the elevation of the least number of threads (one quarter of the warp only), thereby sparing the warp threads and minimizing the efforts of the weaver.

The weaving required 4 shafts threaded from the back to the front for the straight series and from the front to the back for the return series. In the traditional method of weaving, the shafts were operated by means of pedals that the weaver maneuvers with the passage of each shot of weft.

Selvages: These are composed of only two double threads at each selvage,[8] and their construction is quite unusual. The two threads are worked with the warp threads to form a 3:1 twill, their floats being inverted relative to the main twill pattern. The binding of the first thread is next to the last thread of the ground (notice that the twill is incomplete since the selvage consists of only two ends). Nevertheless, this method of construction assures that the weft threads are adequately secured, sometimes by two threads, as at passes III-IV, and sometimes by only the first thread: passes I-II (Fig. 5-A).

At the loom, the same shafts were used for the selvage threads as for the ground, but with different types of heddles. For example, a central-eyed heddle was used for the ground threads and two clasped heddles were used for the selvages. Each selvage thread passes through the upper half (above the linked loops) of the clasped heddles of three different shafts (Fig. 5-B).

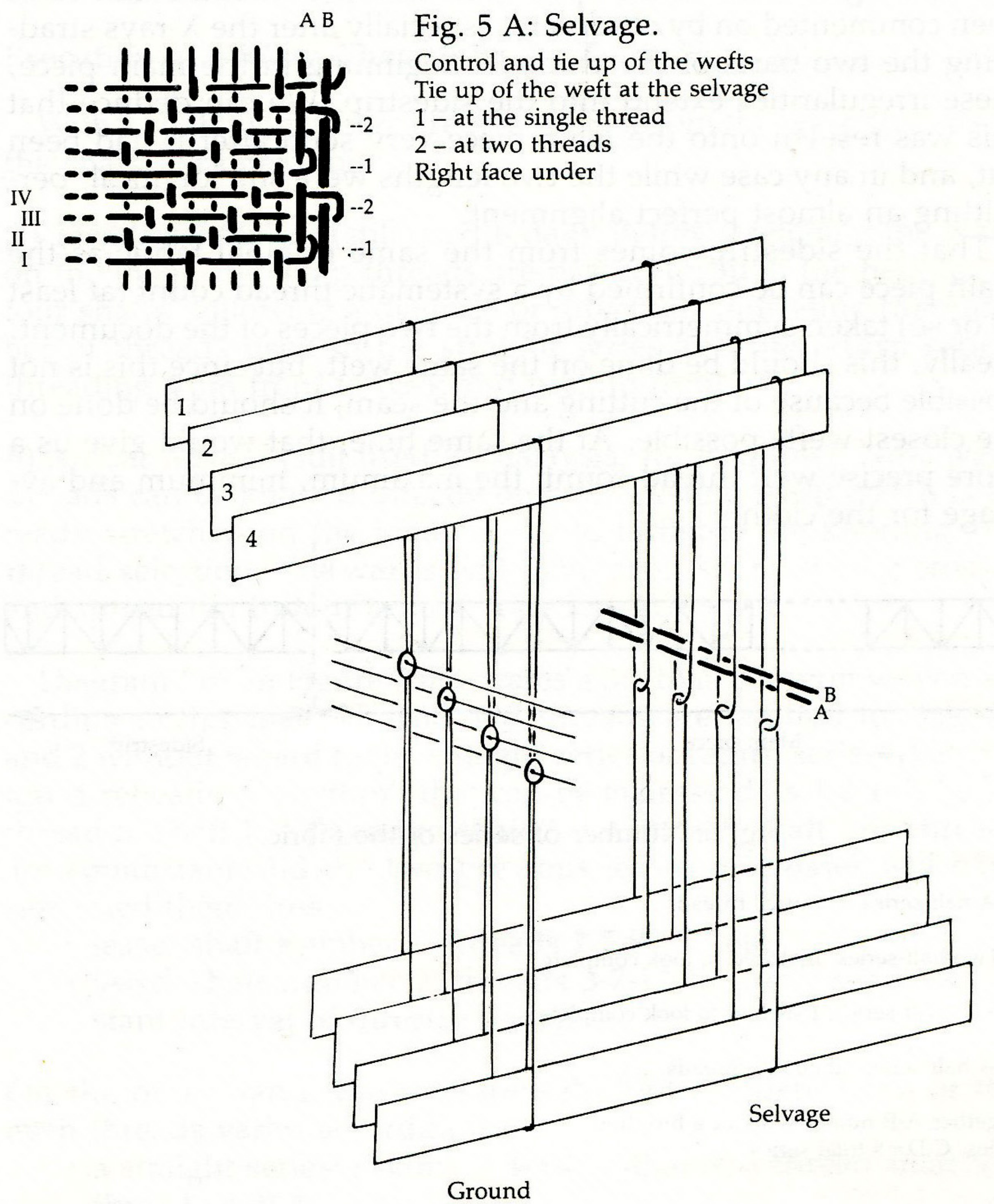


Fig. 5 B: Threading, ground and selvage.

CONSTRUCTION OF THE ORIGINAL FABRIC (Fig. 6)

The main piece appears to be composed of a series of a hundred or so diagonals resulting in fifty repeats of the chevron. It begins with a half-series and seems to end the same way where it is stitched to the sidestrip. The sidestrip is composed of seven diagonals plus an additional half-series at the selvage and probably another half-series at the seam that joins it to the main piece.

The two partial diagonals at the sewn join are oriented in the same direction, which allows us to suppose that the two pieces were re-attached exactly where they had been cut. In this case, there would not have been a rolled edge in this area. However, the sewing does not seem to follow exactly the thread of the diagonal.

The irregularities in the spun weft and the thread count have been commented on by observers, especially after the X-rays straddling the two parts of the shroud.[9] Beginning in the main piece, these irregularities extend into the sidestrip. We can deduce that this was resewn onto the main piece very soon after it had been cut, and in any case while the two lengths were still identical, permitting an almost perfect alignment.

That the sidestrip comes from the same original fabric as the main piece can be confirmed by a systematic thread count (at least 20 or so) taken symmetrically from the two pieces of the document. Ideally, this should be done on the same weft, but since this is not possible because of the cutting and the seam, it should be done on the closest wefts possible. At the same time, that would give us a more precise weft thread count: the maximum, minimum and average for the cloth.

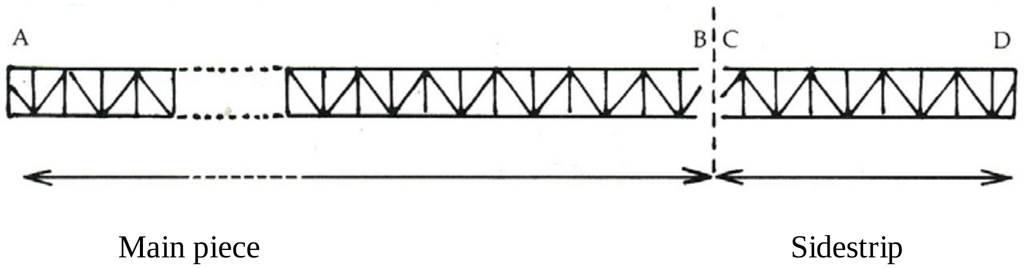


Fig. 6: Number of series of the fabric.

A-A half-series, about 20 threads.

B-Two half-series, matched to look complete.

C-Two half-series, matched to look complete.

D-A half-series, about 20 threads.

Together A-B numbers about a hundred series. C-D =8 total series.

COMMENTS ON WEAVING TECHNIQUES

Weaving Faults: Two types of faults deserve attention:

Type 1: The differences noted between the numbers of threads of a series are typical in ancient fabrics composed of bands or squares and result from errors in counting by the worker. They are often imperceptible and do not merit particular comment, even though there is always interest in spotting them for future comparisons.

Type 2: This type of fault reveals the method used for the threading of the warps. It has already been explained and published,[10] so I will briefly sum up the principle and how it applies to the cloth we are studying.

Execution of a Warp Chevron in 3:1 Twill (Fig. 7-8).

With a shaft loom, there are two ways to join the warp threads to the shafts for operation:

A) *Traditional Method* (still used today): Before stretching the warp on the loom, the warp threads are passed through the heddles of four shafts, following a diagram or directions indicating the number of threads used in the straight series and the return series, threading from front to back and back to front.

B) *Archaic Method* (still used in Malaysia, for example): New warp threads can be knotted directly onto an existing warp which is already stretched on the loom. So as to facilitate the knotting and thread selection, the warps will have been separated by crosses and spread out in four groups, one for each shaft.

Diagram "B" in Figure 7 illustrates a 3:1 twill chevron woven according to this method. The odd threads are knotted to shafts 1 and 2 without regard to the straight series or return series; they follow a repeating "rhythm" that can be expressed as 1-2-1-2, i.e., 1 thread to shaft 1, 1 thread to shaft 2.... On each shaft, the threads are equidistant and the two previous leases or crosses will have separated them thus:

- lease, shaft number 1: threads 1-5-9-13...etc.
- lease, shaft number 2: threads 3-7-11-15... etc. (with a constant interval of three threads).

On the other hand, the repetitive rhythm of distribution of the even threads varies according to:

- a straight series: rhythm 3-4-3-4 ... that is, 1 thread shaft 3, 1 thread shaft 4...
- or a return series: rhythm 4-3-4-3 ... that is, 1 thread shaft 4, 1 thread shaft 3...

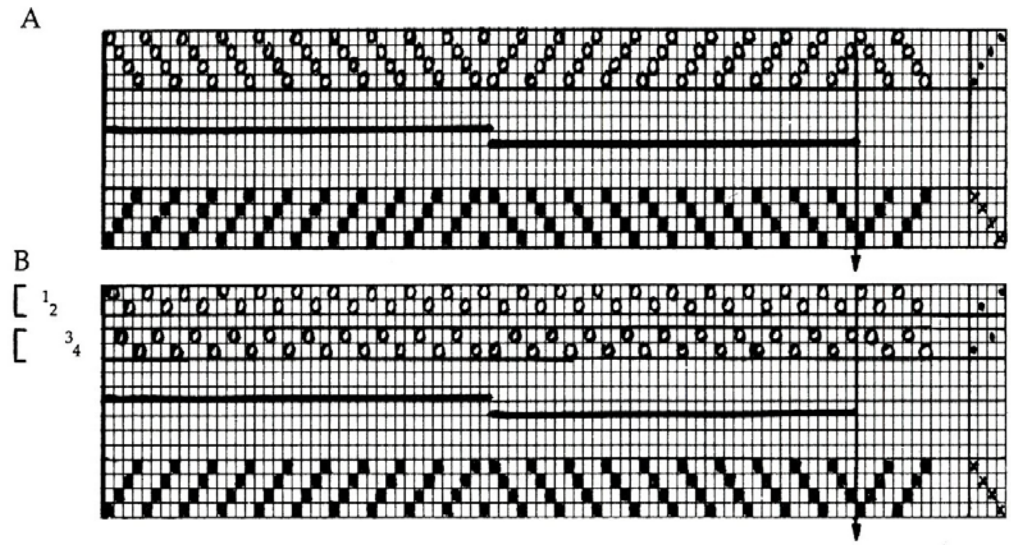


Fig. 7: Two methods, tying up of the threads or knotting of the leases.

The crosses are therefore more complex to accomplish since the interval on a shaft between two neighboring threads varies with the change of series: 1 or 5, whereas it is 3 at the interior of the series.

In this manner, the cross of shaft number 3 selects threads:
    2, 6, 10, 14 ... 38 - 44, 48, 52, 56 ... 78 - 82, 86, 90, 94 ... 118, etc.
while the cross of shaft number 4 selects threads:
    4, 8, 12, 16 ... 40 - 42, 46, 50, 54 ... 80 - 84, 88, 92, 96 ... 120, etc.

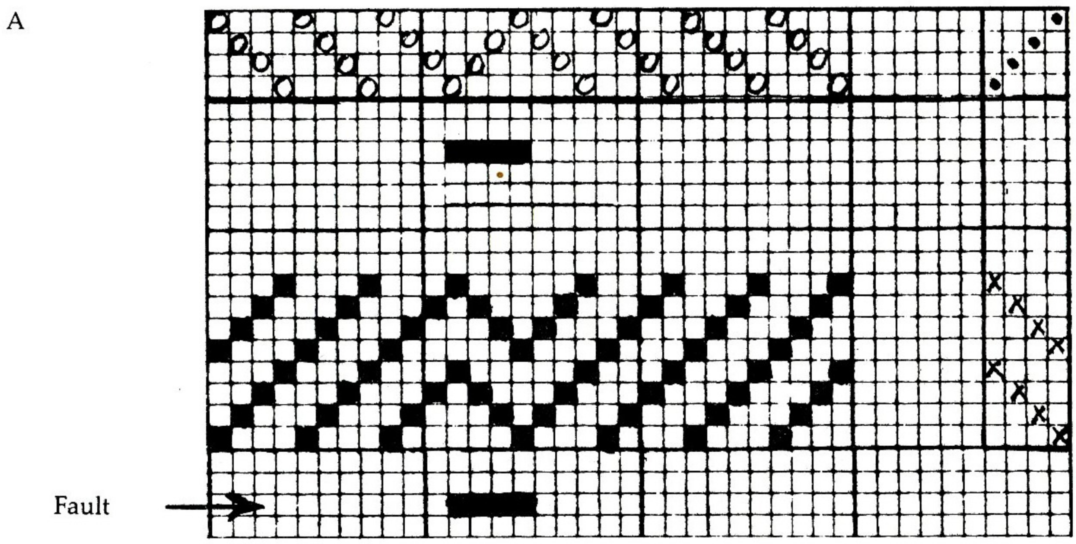
It is easy to see that errors can occur where the crosses are formed, particularly those which will serve to tie shafts 3 and 4.

Figure 8 shows that an error in threading with the traditional method (A), has resulted in a change of direction over at least 4 threads (including points). In the archaic method (B), the error results in a change of direction over at least 5 threads (points included).

Of the two types of faults seen in Figure 4, the implication is that the archaic method was used to make the cloth of the Shroud. Unfortunately, we do not yet know when the modern method began to be used. Daniel De Jonghe[10] has remarked only that this type of fault disappeared in the chevrons of canvas used for paintings of the XVIIIth century. We can only note the comparative interest that their detection can hold.

* * *

In his final section, Prof. Vial compares the Shroud fabric with other ancient examples that have been cited if not always studied at first hand. Many of these examples have been repeatedly published in this same comparative context. As the discussion does not directly concern the description of the sindonic textile, the first paragraphs may be summarized:



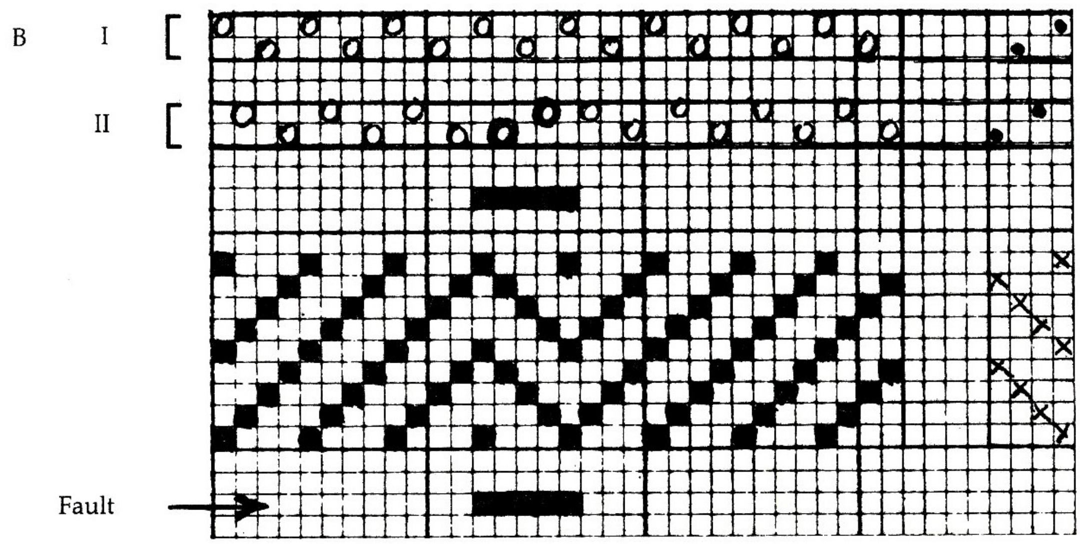


Fig. 8: Small fault of taking in according to the method used.

Egyptian shrouds differ from the Turin Shroud in that they are woven in a tabby; they were fabricated as separate pieces that started with a reinforced edge and ended with fringe: whereas the Turin Shroud is to be considered a fabric woven "by the kilometer". As it has not been possible to expose the ends, one cannot ascertain if there was a rolled hem, but had there been fringe, Prof. Vial opines, some elements would presumably remain. On the other hand, if pieces had been cut from the ends for relics [or for holy icons?] that too might be clarified by direct observation.

As for the herringbone weave; only superficial descriptions have been advanced, irrespective of the technical complexities of the type of loom necessary. There is a fundamental difference between a 2:2 twill and one of 3:1. The herringbone and lozenge weaves are known since the Iron Age, if not earlier, but the fragments discovered are generally 2:2 and-all are wool.[11] The borders of the Antinoe cushions are 2:2 and are wool.[12] Damask *cloth, for example those of Palmyra, Treves, Con they, Ribeauville, Cologne, Holborouh, are "derivatives: of 3:1 twill (or of satin 4:1) but they are all in silk.*[13] *(To return to the text:)*

I have personally analysed a Chinese fabric from the Tan era (618-907) in the New Delhi Museum; a herringbone 3:1 twill in silk.[14] The fabric of Doura-Europas[15] given as a 3:1 twill is, in reality, a damasked lozenge of 2:2 twill in *wool*.[16]

The only herringbone in *linen* so far analysed and published is that cited in note 10. It is very late — second half of the XVIth century — and much simpler than that of Turin. The number of threads per centimeter in its main warp is practically half of the Turin count (19.5 instead of 38) and the proportion of warp/weft reductions is less: 19.5/16 = 1.22 instead of 38/26 = 1.46 for Turin. The important main warp of the latter thus offered a much smoother surface to the reproduction of the image.

If one takes into account the three constitutive elements of a textile — the structure, the primary material, and the reductions of warp and weft — one must acknowledge that the Shroud of Turin is truly "incomparable"....

Professor Vial's article, "Le Linceul de Turin — Étude Technique”, appeared in *CIETA Bulletin* 67, (1989) and is published here by kind permission of the Author and Editors of CIETA (Centre International d'Étude des Textiles Anciens). The technical sections were translated by Jane Merritt, member of CIETA and the Textile,Society of America, and Erica Gibson, French language teacher.

NOTES

1. P. VIGNON: *Le Saint Suaire de Turin*, Masson, 1939, p. 82: cited by numerous authors.

2. *La Sindone, Scienza e Fede*. Atti del II Convegno Nazionale di Sindonologia. CLUEB, Bologna. The book jacket shows a series of 37 threads.

3. IAN WILSON: *Le Suaire de Turin*, Albin Michel, Paris, 1978. The illustration on p. 97 clearly shows two faults of this kind.

4. L. BELLINGER: "Textile Analysis: Early Techniques in Egypt and the Near East", in *Workshop Notes* #2, Textile Museum, Washington, June 1950.

5. WALTER ENDREI: *Evolution des techniques du filage et du tissage*, Mouton, Paris, La Haye, 1968, p. 18.

6. R. J. FORBES: *Studies in Ancient Technology IV*, p. 159 (cited by Endrei).

7. R. PFISTER: *Nouveaux textiles de Palmyre*, Les Editions d'Art et d'Histoire, Paris, 1937, p. 40. YIGAEL YADIN: *The Finds from the Bar-Kochba Period in "The Cave of Letters"*, Israel Exploration Society, Jerusalem, 1963, p. 252. This concerns sackcloth. G. M. CROWFOOT: *Discoveries in the Judean Desert II. Les grottes de Murrabba't*, Oxford, The Clarendon Press, 1961, p. 59.

8. These can only be described as "strings", generally heavy threads joined to the exterior edges of the selvages to reinforce them; but in some ancient fabrics can alone constitute the selvages around which the weft turns (CIETA *Vocabulaire*). Only the right selvage has been completely observed, but the centuries-old rolled hem prevented an exposure of enough of the fabric to make a macro-photograph, which would have permitted confirmation and illustration of this particular crossing. The presence of a selvage on the left was merely ascertained.

9. L. A. SCHWALBE AND R. N. ROGERS: "Physics and Chemistry of the Shroud of Turin. A summary of the 1978 Investigations." Special Report. *Analytica Chimica Acta* 135, 1982, pp. 3-49, fig. 7.

10. DANIEL DE JONGHE: "Particularités de tissage d'une toile attribuée a Martin de Vos", Bulletin de l'Institut Royal du Patrimoine Artistique, Bruxelles, t. XVIII, 1980/1988, pp. 81-92. This painting of *The Last Supper* is on linen with a 3:1 (herringbone) twill weave. Structured with a series of 9 threads straight, 7 threads return, it presents faults of the same type as those studied here. I am not familiar with other linen herringbones cited in the bibliography.

11. H. J. HUNDT: "Vorgeschichtlich Gewebe aus dem Hallstatter Salzberg", *Jahrbuch des R. G. Z. M.*, Mainz, #14, 1967; #56: wool damask, herringbone 2:2. K. SCHLABOW: *Textilfunde der Eisenzeit in Norddeutschland*, Karl Wachholtz Verlag, Neumünster, 1976, figg. 92, 102, 156 etc. Herringbones and lozenges in wool, 2:2 weave. H. MASURE: "Les Celtes dans le nord du bassin parisien:, *Actes du V^e^ colloque tenu à Senlis. Revue archeologique de Picardie* #1, 1983, p. 282, herringbone and lozenge in wool, 2:2 weave. R. ULLMEYER & K. TIDOW: *Die Textil-und Lederfunde der Grabung Feddersen Wierde*, Verlagsbuchhandlung August Lax Hildesheim, 1973, pp. 69-93. Herringbone and lozenges in wool, 2:2 weave (Gallo-Roman period, I^st^-V^th^ c. A.D.).

12. F. GUICHERD: Analyses of the fabrics of Antinoë 26812/19 & 20, at CIETA, Bibliothèque du Musée Historique des Tissus, Lyon. Identical to those found in *Les Portraits d'Antinoë*, pl. III, by E. GUIMET, Hachette, Paris, 1912.

13. D. DE JONGHE & M. TAVERNIER: "Les damassés de la Proche-Antiquite" in *Bulletin du CIETA* #47/48, Lyon, 1978, p. 14. "Les damassés de Palmyre:, op. cit. #54, 1981, p. 20. "Die spätantike Köper 4-Damaste aus dem Sarg des Bischofs Paulinus in der Krypta der Paulinuskirche zu Trier", in *Trierer Zeitschrift*, 40/41, 1977-78, pp. 145-174.

14. K. RIBOUD: "Procedures and Results of a study; Sir Aurel Stein Textile Collection at the National Museum, New Delhi", *Bulletin du CIETA*, #32, 1970-72, p. 24. G. VIAL: "Analyses techniques des échantillons", ibid. p. 40.

15. L. BELLINGER: "Textile Analysis: Early Techniques in Egypt and the Near East", *Workshop Notes*, paper 3. Textile Museum, Washington, April 1951. The fabric described as a 1:3 twill is, in fact, a damasked lozenge in 2:2 twill. Cf. note 16.

16. L. BELLINGER: *The Excavations at Doura-Europas*, Part II, The Textiles, #36, p. 2 & 22, pl. XIII & XXXIII-D2.