The Unconscious Structural Properties of Aesthetic Shapes Produced by Hand-Beam of Japanese Shrines: Relationship between the Decoration Patterns of Sculptures and the Latent Dynamic Characteristics

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Keywords: Dynamic characteristics, Aesthetic shape, Caved pattern

Summary

In this paper, as a case study, it was aimed to investigate the dynamical characteristics of the decorated beams of Japanese temples and shrines to find out the relationship between the dynamical characteristics and the decoration pattern carved on the beams. It was assumed that the carved patterns: KARAKUSA that have been carved traditionally by processional carvers on the decorated beams might be affected by a latent dynamism. The decorated beams called as "KOURYO" were investigated to elucidate a relationship between the KARAKUSA patterns and the stress distributions under normal gravity conditions of the decorated beams. The contours and the patterns of the decorated beams were collected through field surveys. And, the stress distributions of the beams were calculated by using a structural analysis application: FEM. Besides, an interview with a professional carver of the KARAKUSA patterns was carried out in order to find out how the carver would be influenced by the latent dynamism when he carved the patterns. And, the structural analyses were carried out to the thirteen decorated beams: TOSYOGU at Ueno Tokyo, HOKEKYOU temple at Chiba and so on. As a result, the directions of which the carved patterns developed from the end to the midpoint of the beams almost coincided with the directions of the distribution of the stresses predicted in the beams. Finally, it was confirmed that the KARAKUSA patterns might be indirectly but strongly affected by the stress distribution, which could never be directly sensed through the carvers' eyes.

1. Introduction

We can see various decorations in shrines and temples in the world. Many of them are well formed and have an esthetical harmony with the decorations. In particular, we have been taking an interest in a decoration pattern of the beams in Japanese temples and shrines, which has been carved at nearby the intersection between the beam and the column. The beam has been termed as the KOURYOU, which had been originally a curved beam. And the pattern has been called as the KARAKUSA (Tanaka, 1995).

It may be not difficult that we could recognize that the KARAKUSA pattern might have been carved in the KOURYOU under consideration of a kind of dynamism. We tried to investigate a relationship between the KARAKUSA pattern and the latent dynamism of the beams. Basically the

beams are one of the structural members in the temple and shrine structures. So, it is natural that there would be an important dynamic characteristic in the beam. However, until the present time, it has been seemed that there would be no relationship between the sculptures and the dynamic characteristic. We have been feeling that there must be a relationship between them. So, we have assumed that the sculptures might be carved according to the latent recognition to dynamic properties in the beams. We have also thought that the latent dynamical recognition would mean intuitively sensing the stress distribution in the beams.

Figure 1: KOURYOU carved the KARAKUSA pattern

Figure 2: Curved beams as an original shape of KOURYOU

2. Curved beams: KOURYOU

Figure 2 shows the curved beams in a temple that are of comparatively early ages in the history of the curved beams. The structural beams have been called KOURYOU, traditionally. The KOURYOU is a curved beam like a rainbow. The roles of the KOURYOU were to receive the weight of the roof and the ceiling and to connect the main building and the eaves (Fig.2-2). It has been understood that the effects of the curving should be two effects following:

i) The dynamic effect reinforces the strength of the beams.

ii) The visual effect reforms the visual sagging down in the central part of the beams.

Like this, the shapes had tended to be curved and had not been decorated by any patterns in the early times of the history of the KOURYOU.

3. Changes in the shapes of the KOURYOU

Figure 3 shows how the shapes of the KOURYOU have changed with the times. Generally speaking, we may be able to say that the shapes had changed from the arch to the straight beam. The characteristics of the changes would be able to be summarized as the follows: -

- Outline: From an arch to a linear beam
- Cross section: From a trapezoid hand standing to a circle, and to a rectangular
- Structure: From a truss to a rigid frame
- Pattern: Appearance and development of the KARAKUSA pattern

Basically, the shape of the beam had been dominated by which the material of the beam was wood and the size of the beam would be limited by the quality of the material. We may be able to understand that the shape of the beams had come to influence the aesthetic shapes of the shrines and temples as a result of optimizing woods for constructing the structure shapes. We can also understand that the curved beam with no schematic decoration had born as a result of the optimization. While, according to large scaling of the shrines and temples, it had become difficult to construct the bigger shrines and temples with such curved wooden beams.
Therefore, the shapes of the structures had come to be dominated by basically linear structural members. It may be easy that we understand that the visual sagging down would come to be an decorated pattern KARAKUSA might be produced as a complement of the visual imperfectness (Fig.4). We may also be able to think that the visual imperfectness would intuitively connect to a dynamic imperfectness: stress concentration and so on. In other words, the KARAKUSA pattern would play an important part in visually completing the shapes of the beams, which may have the dynamic imperfectness.

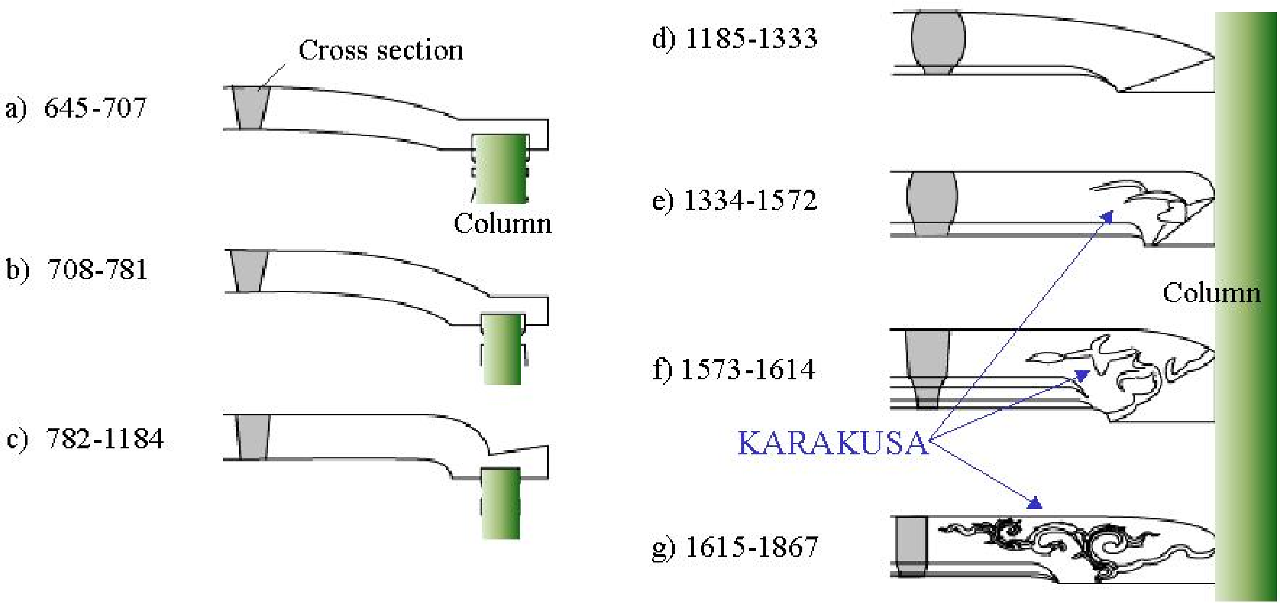


Figure 3: Changes in the shapes of the KOURYOU (Mae, 1980)

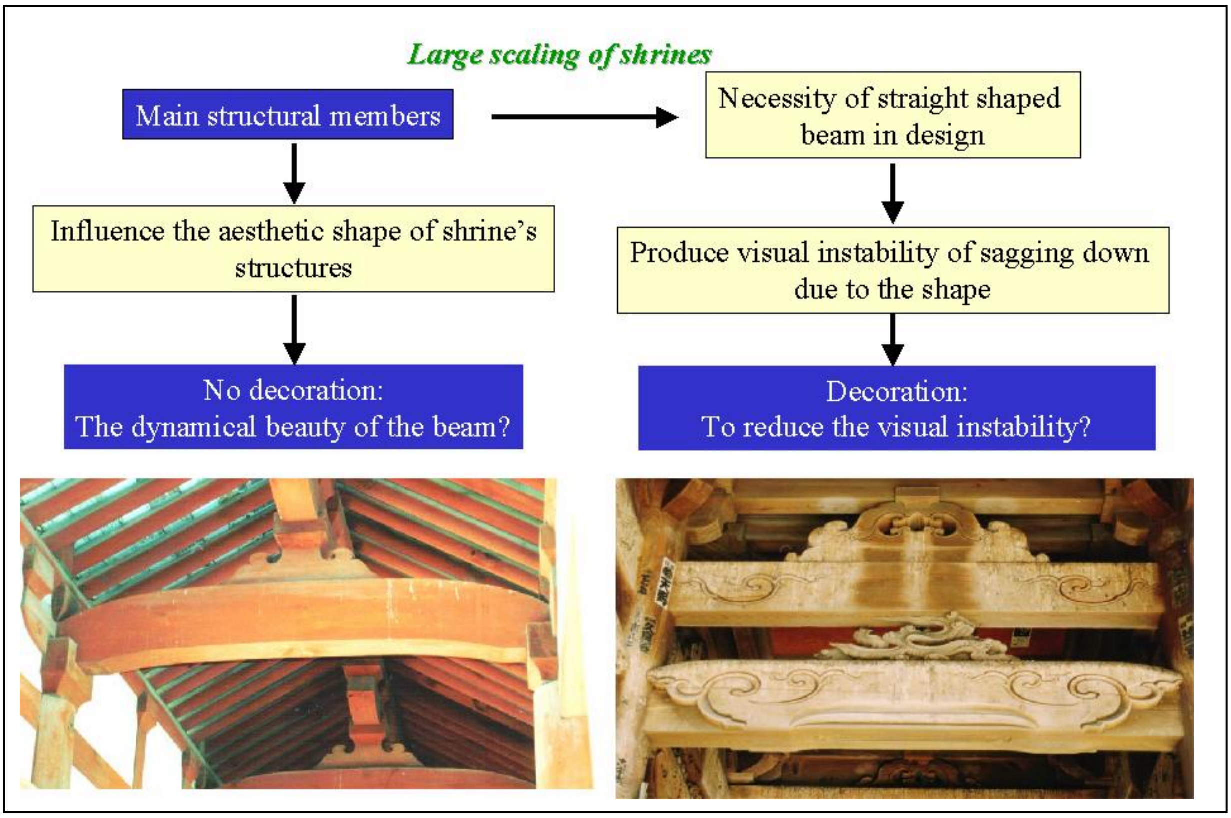


Figure 4: Development of the KARAKUSA pattern

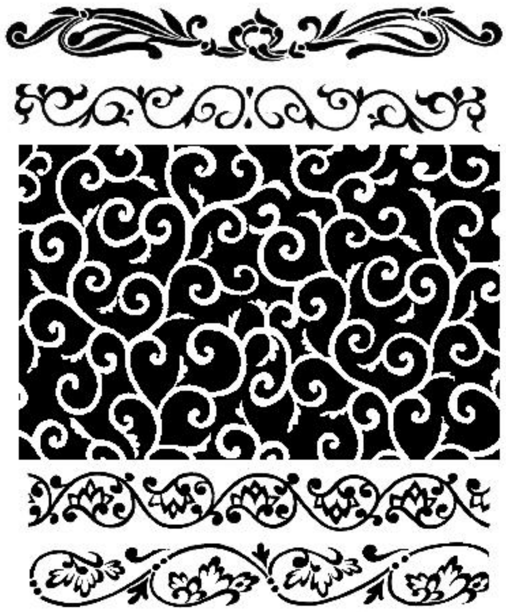


Figure 5: KARAKUSA

4. Interview with a professional carver

We also carried out an interview with a professional carver to know how he would carve the KARAKUSA pattern and what the carver would feel while he would carve it. The followings were suggested through the interview: -

i) KARAKUSA pattern had been established as a traditional form (Fig.5)(Mitsui, 2000).

ii) However, the design (e.g. position and shape) is up to the carvers' aesthetic sense.

iii) The carvers may intuitively form the pattern in consideration of a latent dynamism of the beams.

iv) The patterns formed according to the dynamism would be beautiful shapes.

As a result, we can confirm that the KARAKUSA pattern on the beams would be affected by the consciousness to the dynamism that might be exiting in the beams. Although the patterns have been carved according to an intuitive esthetical sense, we may be able to think that the intuitive esthetical sense had been affected by an invisible dynamic characteristic: the stress distribution.

5. Structural analysis of the decorated beams

5.1 Selected decorated beams

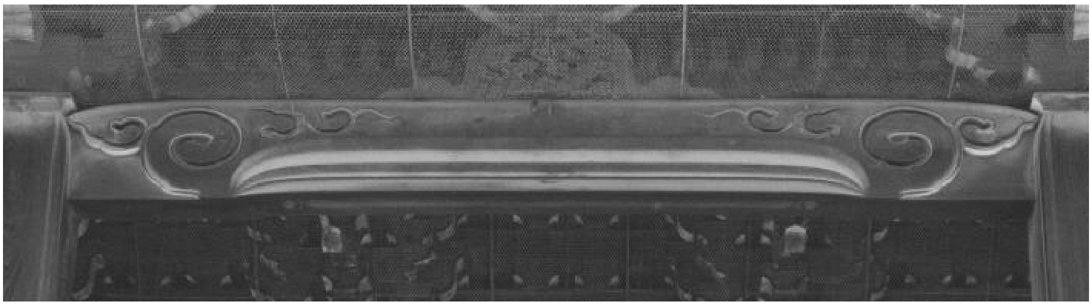
Structural analyses using ANSYS Ver. 5.6 were carried out to investigate the relationship between the KARAKUSA patterns and the stresses distributed in the decorated beams. The thirteen decorated beams were selected to calculate the stress distribution that would be induced by general gravity conditions. The beams were of from the early Edo era to the early Meiji era, and they had mature forms of the KARAKUSA pattern. Figure 6 shows some of the thirteen beams.

5.2 Estimation of the stress distribution

Figure 7 shows the stress distributions of the three results in the thirteen results calculated through ANSYS solver (Appendix A). It is showed in the results that the comparative high compressible stresses distribute over the area colored with light yellow. These stress distributions show the distributions of the principal compressible stress in each decorated beam. General speaking, the distribution of the KARAKUSA patterns tends to consistent with the distribution of the compressible stress distribution in each decorated beam. Figure 8-1 shows the distribution of principal stresses with such arrows at each estimation point of the stresses. And, figure 8-2 schematically describes the principal axes of the compressible and tensile stresses as continuous lines together with the KARAKUSA pattern. As a result, it is suggested that both the global and local directions of the pattern would be almost consistent with the directions of the principal axes of the stresses.

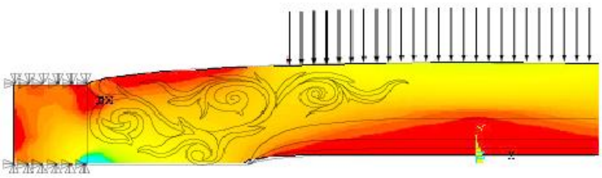
(a) TOYOKAWAHONDEN (b) SUWA Big Shrine

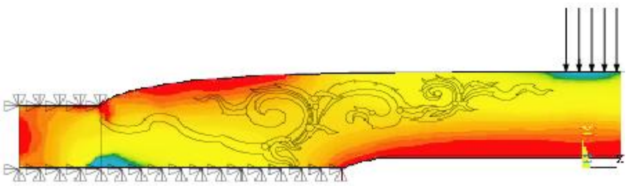
(c) SHIRAHIGE Shrine (d) HOKKEKYOU Temple



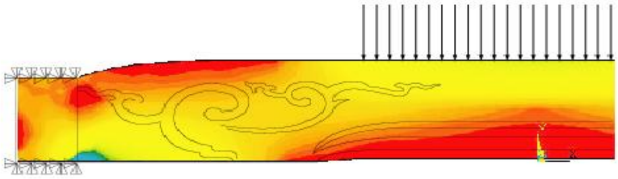
(e) AMIDADO

Figure 6: Selected decorated beams





(a) SAIDAI Temple (b) SUWA Shrine



(c) HOKKEKYOU Temple

Figure 7: Distributions of the principal compressible stresses

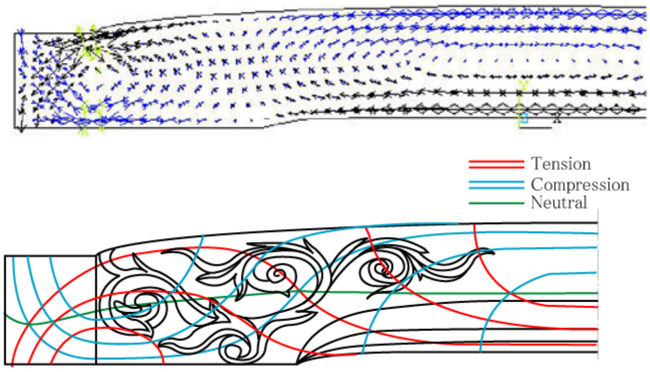


Figure 8: Principal axes of the stresses and the continuous stress lines

6. Estimation of the patterns: Distribution of the D-values

Figure 9 shows the distribution of D-value (Appendix B). The results in A-area show that the tangential lines of the pattern are comparatively coincident with the direction of the principal tensile stress, and the results in B-area show that the tangential lines would tend to intersect the directions of the both principal stresses at about 45 degree. Finally, the results in C-area show that the tangential lines of the pattern agree with the directions on the principal compressible stress. As a result, it was suggested the followings: -

i) The compressible stress distribution roughly matched with the patterns.

ii) The tangential line of the pattern matched with the direction of the principal axes of compressible stress and tension.

iii) The tangential line intersected the principal axes of compression and tension at 45 degree at where the whorl of the pattern located.

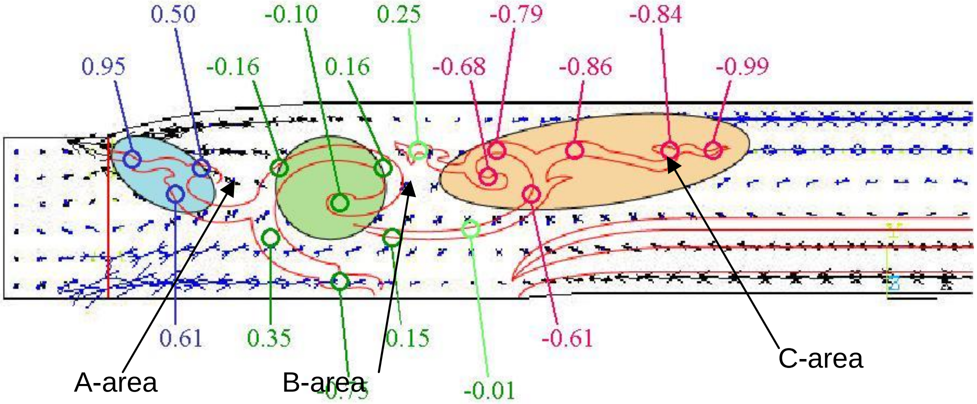


Figure 9: Distribution of the D-values

7. Principal stress distribution in a 3-D FEM model

A 3-D FEM model was constructed to confirm whether the results obtained in the 2-D analyses were almost valid to the real decorated beams. Basically, the process of modeling the 3-D model was similar to one of the 2-D model. The analysis conditions were same. Figure 10 and 11 show the real beam and the principal stress distribution of the 3-D FEM model constructed according this photograph of the beam. As a result, it was suggested that the 3-D model realistically reproducing the decorated beam also show the similar relationship between the KARAKUSA pattern and the stress distribution in the 2-D beam.

Figure 10: Big KOURYOU in the main temple of SAIDAIZI

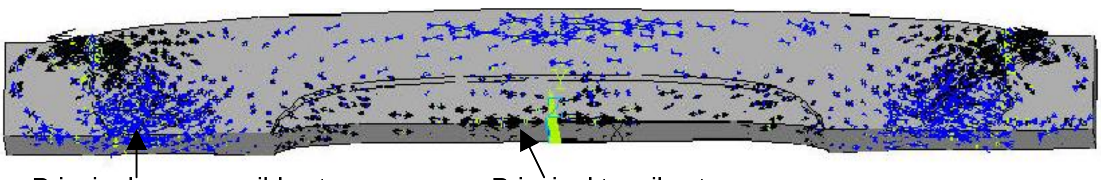


Figure 11: Principal stresses in the 3-D FEM model

8. Conclusions

We investigated the dynamic characteristics of the decorated beams of Japanese temples and shrines as important factors that would influence how the professional carvers would form the KARAKUSA patterns. We have assumed that there would a relationship between the dynamic characteristics and the patterns. While, we have known that the sculptures on the beams have been experimentally and intuitively carved the KARAKUSA patterns and that the patterns have been inherited as a tradition through an interview with a professional carver. Furthermore, we could suggest the possibility of that there would be the relationship between the KARAKUSA patterns and the stress distributions of the decorated beams through the structural analyses with the D-value. The D-values, which were defined in this study, could numerically describe the relationship between the directional characteristics of the stress distributions and of the KARAKUSA patterns of the decorated beams. We could summarize the conclusions with the followings: -

i) The KARAKUSA patterns matched with the latent dynamism: the principal stress distribution.
ii) The KARAKUSA patterns might be inevitably sculptured in order to provide visual stability of the KOURYOU.
iii) There may be some relationship between the sculptural design and the structural dynamism.

9. Future works

This study was carried out in order to examine the unconscious structural properties of aesthetic shapes produced by hand. Such shapes which have been produced in like a small-scale or regional handicrafts business should suggest some important ideas to people who would develop and improve our environments to live better. In other words, we can find out that these shapes are of well fitting for the environments, may be, with no waste. For example, these photos show two farming tools in Taiwan and Japan, respectively (Fig.12-1, 12-2). Although the shapes have not been numerically investigated yet, the outlines of the shapes could obviously match with the stress distributions which would be induced in the tools under the dynamic conditions in daily use. The matching between the shapes and the internal forces induced by some external forces and gravity might mean important facts which could improve our present industrial techniques with many advanced suggestions. Because, the natural or organic shapes that were well adapted to environments surrounding the shapes could not be reproduced very well through the automated industrial processes to produce something, in general. Therefore, I believe that we have to examine the other shapes which have been produced by hand as well in order to find out some essential ideas for creating products, as our future works.

Figure 12: Farming tools

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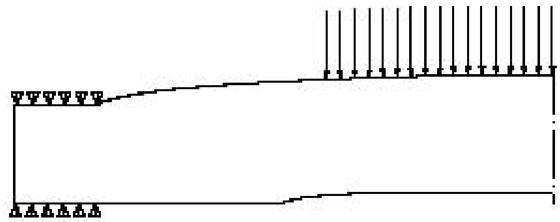
Appendix A
Constructing the 2D－models of the decorated beams

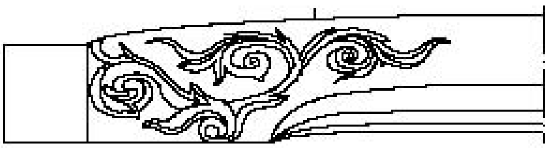
The contours of the shapes and the patterns of the thirteen beams were traced from the photographs (Fig.7-a). The contours were applied to construct 2D-model by using the ANSYS. The following conditions were defined as the analysis conditions.

- Element type: 2-D Solid element;
- Thickness defined according to each real thickness of the beams;
- Materials: E=900Kg/cm^2, Poisson's ratio=0.2;
- Boundary condition 1: Constrict only vertical direction at the connection between the beam and the column;
- Boundary condition 2: Completely fixed with all direction

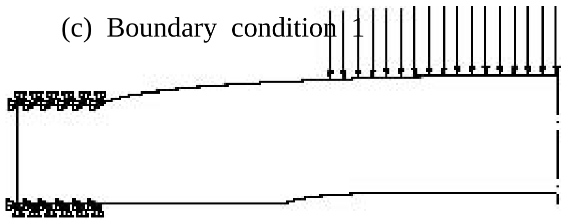
(a) Original photograph



(c) Boundary condition 1



(b) Traced contour and pattern



(d) Boundary condition 2

Figure 7: Tracing contour and pattern of the shape

Appendix B
Definition of the D-value

In order to estimate the directional characteristic of the KARAKUSA patterns the D-values calculating how the tangential directions of the patterns would be coincident with the directions of the stress principal axes were defined as the following equation,

$$D = (s_1/S)\cos(\mathrm{Theta}_1) + (s_2/S)\cos(\mathrm{Theta}_2),$$

where s_1: tensile stress (>0); s_2: compressible stress(<0); $S = sqrt(s_1^2+s_2^2)$;

$Theta_1 + Theta_2 = Pi/2$.

The relation between D, s_i, and Thetas is described in Figure B-1.

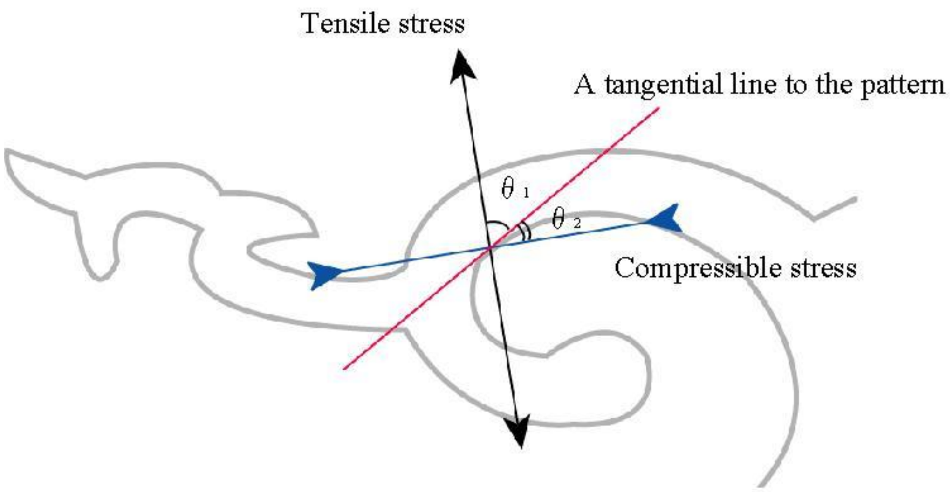


Figure B-1: s_i, $Theta_i$ and D

Figure B-2 also shows if the direction of the tangential line is close to the direction of the principal compressive stress, then the D would be close to minus one, and if the cross angle is close to 45degree, then the D would be zero. And finally, if the direction of the tangential line is close to the direction of the principal tensile stress, then the D would be close to one.

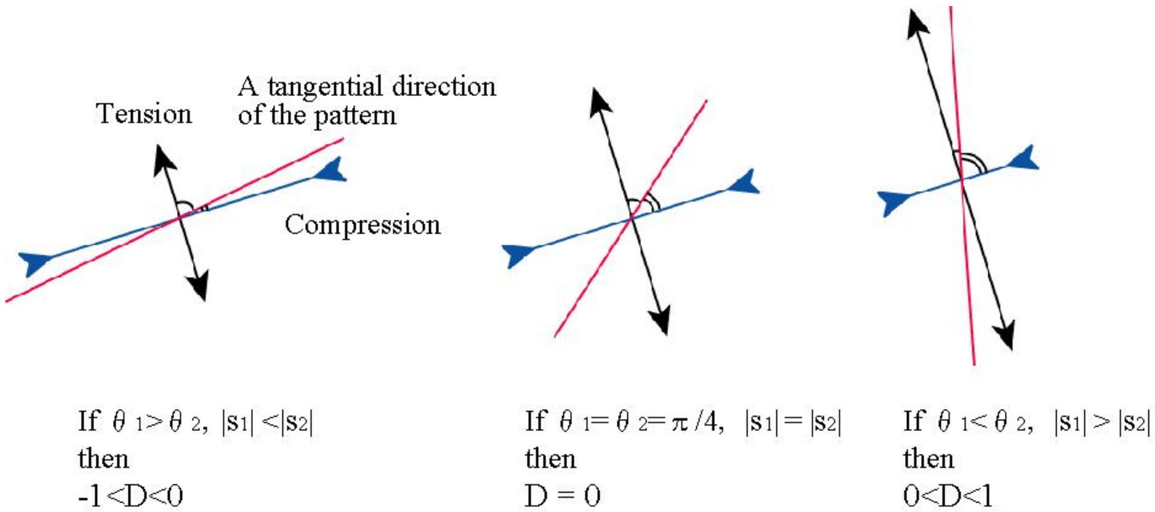


Figure B-2: D-values