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RESULTS OF DIRECT SHEAR TESTS ON SMALL BLOCK COLD SPRING QUARRY SPECIMENS

RAND JACKSON AND ALFRED ANNOR

CANADIAN MINE TECHNOLOGY LABORATORY

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by

Rand Jackson* and Alfred Annor*

ABSTRACT

The ability of an underground repository to isolate high level radioactive waste will depend largely on the host rock and the prevailing joint systems. Difficulties in assessing the mechanical properties of the joints has lead Atomic Energy of Canada Ltd. (AECL) to issue a contract to Terratek Inc. of Salt Lake City, Utah to provide a model to characterize the mechanical and hydraulic behaviour of rock joint systems.

The resulting Barton-Bandis Joint Model (Barton and Bakhtar, 1983) was used to characterize 139 specimens obtained from AECL's underground research laboratory lease area. A test program is currently underway to verify predictions made by the model both in terms of peak shear strength and ability to scale to in situ conditions.

This report presents a summary of the results obtained during direct shear testing of small scale specimens (approx. 5 cm. X 10 cm.). For tests conducted under self weight normal stress (approx. 0.037 MPa), a mean peak shear strength of 160 MPa ($\sigma^2 = 79$) with a mean displacement to peak of 0.08 cm. ($\sigma^2 = 0.06$) was observed. Specimens tested under a normal stress of 0.10 MPa exhibited a mean peak shear strength of 240 MPa ($\sigma^2 = 50$) and a mean displacement to peak of 0.08 cm ($\sigma^2 = 0.06$). These will eventually be compared to model predictions and the results of shear tests on larger scale specimens cut from the same joint.

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*Research Officer, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada, Ottawa, Ontario.

Keywords

Mechanical Rock Properties, Joint Properties, Joint Model, Peak Shear Strength, Lac du Bonnet

RÉSULTATS DES ESSAIS DE CISAILLEMENT DIRECTS SUR DES ÉCHANTILLONS DE PIERRE DE TAILLE PROVENANT DU PETIT MASSIF ROCHEUX D'UNE SOURCE D'EAU FROIDE

par

Rand Jackson* et Alfred Annor*

RÉSUMÉ

La capacité d'un entrepôt souterrain d'isoler des déchets hautement radioactifs dépend principalement de la roche encaissante et des systèmes de diaclases qui y prévalent. En raison des difficultés que présentait l'évaluation des propriétés mécaniques des diaclases, L'Énergie atomique du Canada Ltd. (EACL) a chargé Terratek Inc., de Salt Lake City Utah, du développement, en sous-traitance, d'un modèle pour caractériser le comportement mécanique et hydraulique des systèmes de diaclases.

La société a mis au point le modèle Barton-Bandis (Barton et Bakhtar, 1983) qui a été utilisé pour caractériser 139 spécimens de roche provenant du secteur occupé par le laboratoire de recherche souterrain de L'EACL. Un programme expérimental pour vérifier les prédictions faites par le modèle relativement à la résistance maximale et à sa capacité d'adaptation aux conditions in situ, est en cours.

Le présent rapport comprend un résumé des résultats obtenus pendant les essais de cisaillement en direct réalisés sur de petits spécimens d'une dimension approximative de 5 cm. X 10 cm. Pendant les essais menés sous contrainte naturelle résultant du poids des terrains susjacents (approximativement 0,037 MPa), on a pu observer une résistance maximale moyenne au

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*Chercheur scientifique, Laboratoires de recherche minière. CANMET, Énergie, Mines et Ressources Canada, Ottawa (Ontario).

Mots-clé

Propriétés mécaniques des roches, Propriétés des diaclases, Modèle pour caractériser les propriétés des diaclases, résistance maximale au cisaillement, Lac du Bonnet.

cisaillement, de 160 MPa (σ^2 = 79), accompagnée d'un déplacement moyen jusqu'à une résistance maximale de 0,08 cm. (σ^2 = 0,06). Les spécimens soumis à des essais sous une contrainte naturelle de 0,10 MPa ont démontré un taux moyen de résistance maximale de 240 MPa (σ^2 = 50) accompagné d'un déplacement moyen jusqu'à une résistance maximale de 0,08 cm. (σ^2 = 0,06). Ces valeurs seront éventuellement comparées aux prédictions dérivées du modèle et aux résultats des essais de cisaillement sur des spécimens de plus grande dimension provenant de la même diaclase.

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1. INTRODUCTION

The mechanical behaviour of a rock mass involves the combined effects of the intact rock material, as well as the prevalent joint systems. A good understanding of both is required before the appropriate constitutive models can be developed to represent overall rock mass behaviour. In view of the difficulties associated with the quantitative evaluation of rock joint properties on the basis of existing techniques, a contract was issued to Terratek Inc. of Salt Lake City, Utah to provide a mechanical and hydraulic model for characterizing rock joint systems. The contract was fully discharged in 1983 and, as specified, it outlined a coupled mechanical/hydraulic joint model as well as a methodology for collecting field data as input.

The Barton-Bandis Joint Model (Barton and Bakhtar, 1983) has subsequently been used to characterize 139 joints found in core samples obtained from the Whiteshell research area. Analysis has yielded estimates of joint wall compressive strength (JCS), joint roughness coefficient (JRC), residual friction angle (ϕ_r) and peak joint shear strength under normal stresses ranging from .001 to 100 MPa (Jackson et al., 1985). Additionally, the model has provided a method of determining scaling factors by which laboratory results may be used to estimate in situ joint properties.

A program is now underway to verify predictions made by the model in terms of shear strength and dilation with shear displacement in laboratory specimens. Additionally, large scale joint property estimates made using the scaling factors suggested by the model will also be studied. Generally, the study involves taking a large jointed specimen and dividing it into three sample suites with specimen lengths of 10 cm, 15 cm and 30 cm and a length to width ratio of 2. The samples are initially characterized using the Barton-Bandis model and the joint property estimates made. The three sizes are then subjected to direct shear tests where force, displacement and dilation are measured simultaneously. To date, 13 small scale samples have undergone characterization and direct shear testing at the Canada Centre for Mineral and Energy Technology's (CANMET) Elliot Lake Laboratory.

It is the purpose of this report to briefly outline the testing procedure used in this study and to summarize the results of the small scale direct shear tests. Comparisons of actual and predicted values will be made after the completion of large scale testing.

2. SPECIMEN IDENTIFICATION

All test specimens used in this program have been obtained from the Cold Spring Quarry located just outside of Pinawa, Manitoba. A 1.83 m diameter calyx core containing a single, through-going fracture was drilled at this location. The samples were greyish pink in colour and can generally be described as granitic in composition, although no detailed petrographic analysis has yet been completed.

3. DESCRIPTION OF TEST MEASUREMENTS

Fifteen small scale samples measuring approximately 5 cm wide, 10 cm long and 8 cm high were cut from the original core such that the fracture passed through the center of the samples. Two specimens, numbers 2S and 6S were damaged during sample preparation and could not be tested. The remaining joint surfaces were subsequently traced and digitized to obtain their contact areas.

Eleven samples proved suitable for characterization using the Barton-Bandis model; the remainder of the samples were sufficiently rough to prevent sliding before toppling occurred. The intact compressive strength used in the model was obtained by performing uniaxial compressive tests on four samples cored from the original sample block. Samples were then cast in molds sized to fit CANMET's small scale shear box (Gyenge and Herget, 1977).

The shear box utilizes a screw jack for load application and was operated at a constant displacement rate of approximately 0.25 cm/min throughout testing. The load was measured using an in-line proving ring fitted with a linear variable differential transformer (lvdt) to provide an analogue output of ring deformation. Shear and normal displacements were also measured using lvdts which in turn were connected to a Hewlett Packard X-YY recorder.

Normal stress was applied using a dead load system which included a yoke, that rested on a ball and socket joint attached to the upper shear box. Having determined the area of the joint surface, sufficient load in the form of lead weights is added to the yoke to apply the desired normal pressure. Samples were tested at two levels of normal stress. The first level of normal stress used was the result of the aggregate weight of the upper block, grouting material, upper shear box and yoke (referred to in this document as self weight). The second level of normal stress used for the measurements was equal to 0.1 MPa.

Prior to testing, it was discovered that electrical noise from the proving rings lvdt was sufficient to preclude the use of the X-YY recorder, for continuous monitoring of the load signal. The problem was circumvented by connecting a volt meter to the lvdt. Readings were then taken at ten second intervals and the corresponding levels of shear and normal displacement on the output of the X-YY recorder were marked.

4. DATA SUMMARY

Table 1 contains individual information on specimen dimensions, contact areas, peak shear strength and displacement to peak, for self weight tests and tests conducted at a normal stress of 0.10 MPa. Figures 1 through 13 are computer generated plots of shear stress and normal displacement versus shear displacement for self weight tests; while Figures 14 through 26 illustrate a similar information for tests conducted under a 0.10 MPa normal stress.

For tests conducted under self weight normal stress (approx. 0.037 MPa), the mean peak shear strength is 160 KPa (σ^2=79) with a mean displacement to peak of 0.08 cm (σ^2=0.06). Specimens tested under a normal stress of 0.10 MPa exhibit a mean peak shear strength of 240 KPa (σ^2=50) and a mean displacement to peak of 0.08 cm (σ^2=0.06).

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Table 1 - Summary of sample dimensions and joint properties

			Contact	Sn = self weight		Sn = 0.10 MPa	
Specimen no.	Length (cm)	Width (cm)	area (cm^2)	Peak shear strength (kPa)	Displacement to peak (cm)	Peak shear strength (kPa)	Displacement to peak (cm)
1S	10.14	4.96	50.31	351 (.036)**	0.22	125	0.23
3S	10.22	4.93	50.38	125 (.036)	0.10	716*	0.00
4S	10.26	4.88	50.12	1289* (.036)	0.18	262	0.13
5S	10.34	4.87	50.33	235 (.036)	0.00	248	0.07
7S	9.90	4.72	46.74	198 (.038)	0.00	300	0.06
8S	9.76	4.81	46.98	137 (.038)	0.07	244	0.13
9S	9.67	4.61	44.60	226 (.040)	0.08	276	0.07
10S	9.49	4.79	45.54	158 (.040)	0.00	318	0.08
11S	10.20	4.92	50.11	107 (.038)	0.09	238	0.00
12S	10.20	4.84	49.39	91 (.037)	0.06	205	0.10
13S	10.09	4.86	49.10	90 (.037)	0.10	203	0.08
14S	10.07	5.03	50.71	116 (.038)	0.10	241	0.07
15S	10.01	5.42	54.24	87 (.034)	0.09	226	0.07

*values treated as outliers

**bracketed numbers refer to actual normal stress in MPa

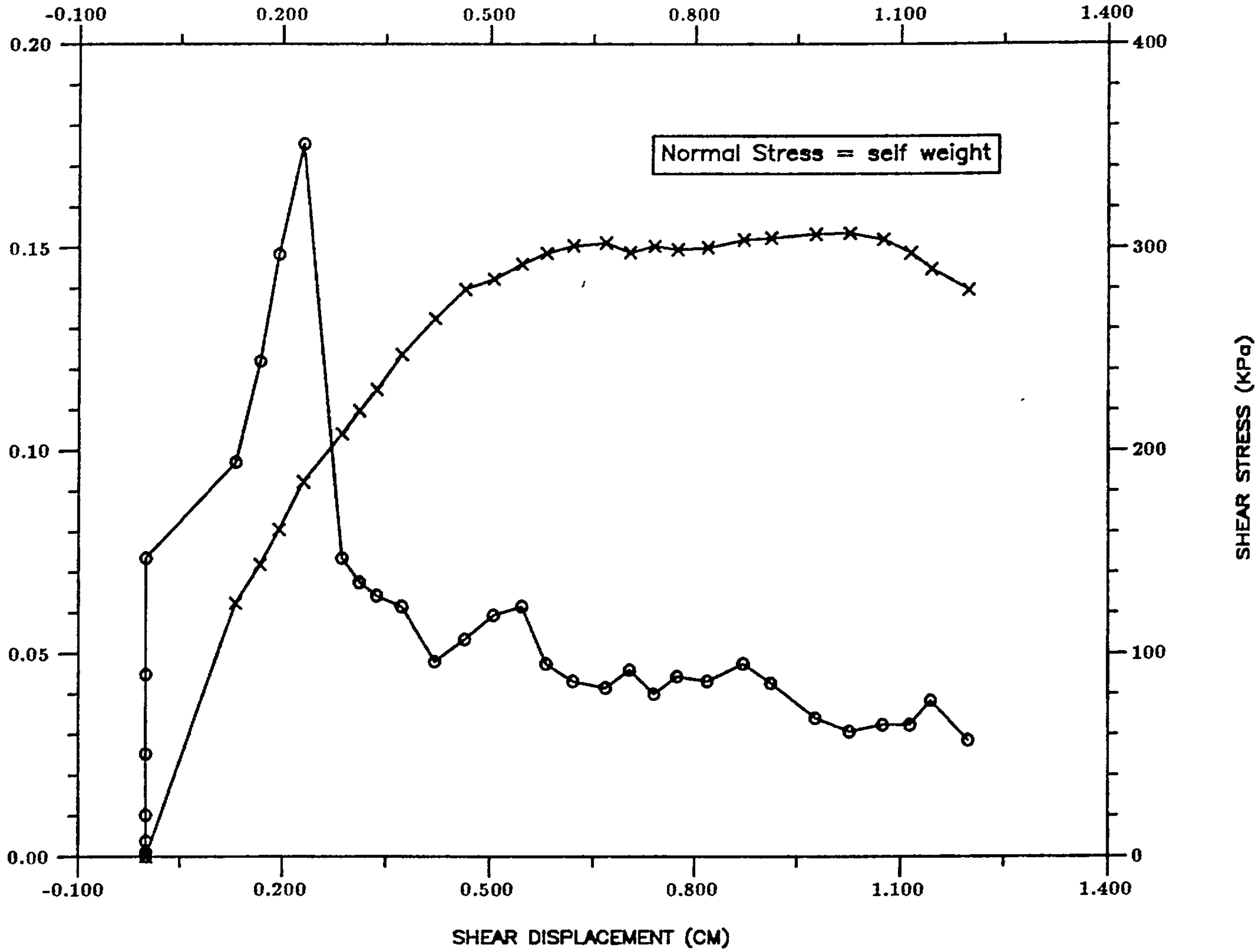

FIG 1: Shear test results of Cold Spring Quarry joint specimen no. 1S

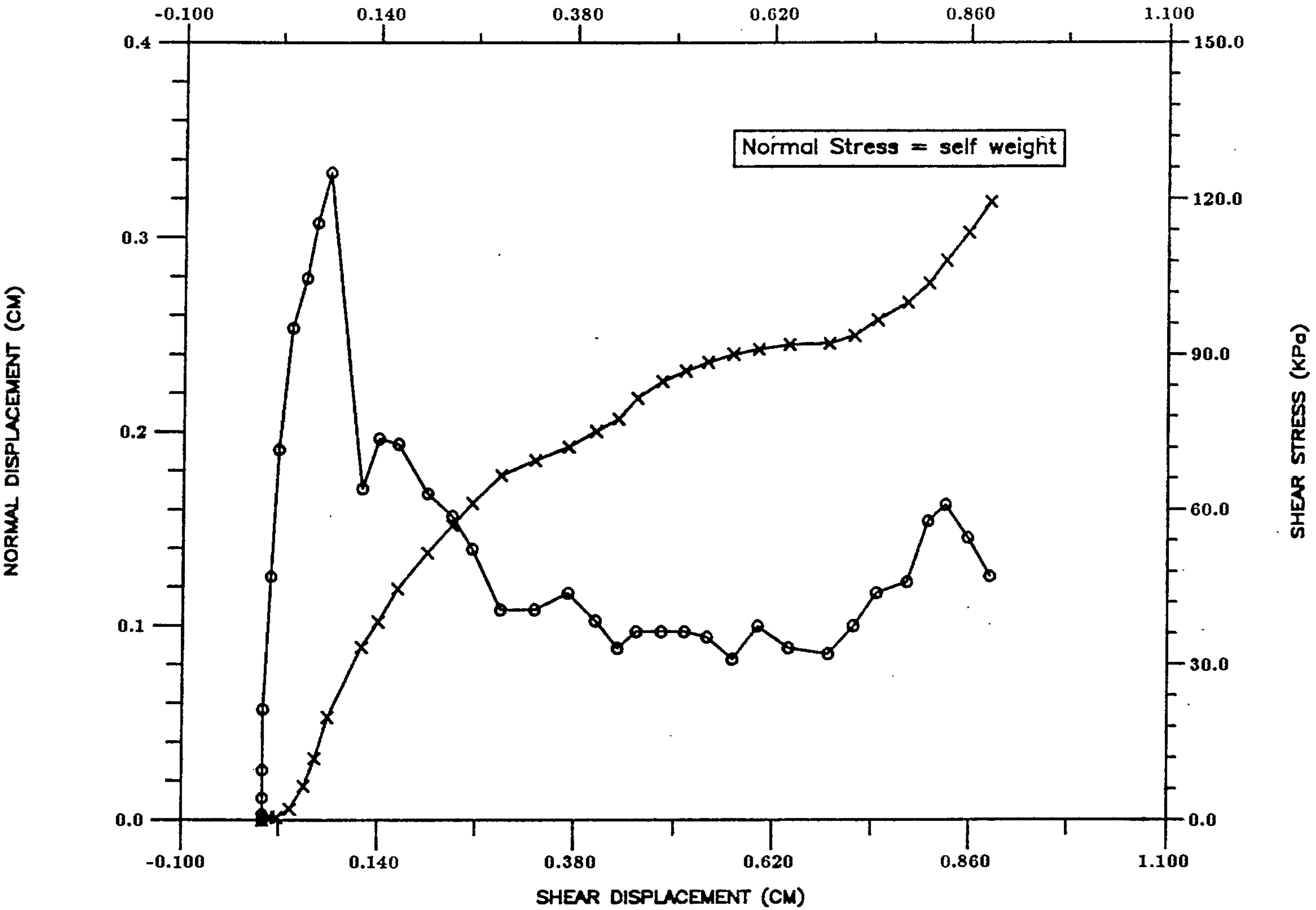

FIG. 2 : Shear test results of Cold Spring Quarry joint specimen no. 3S

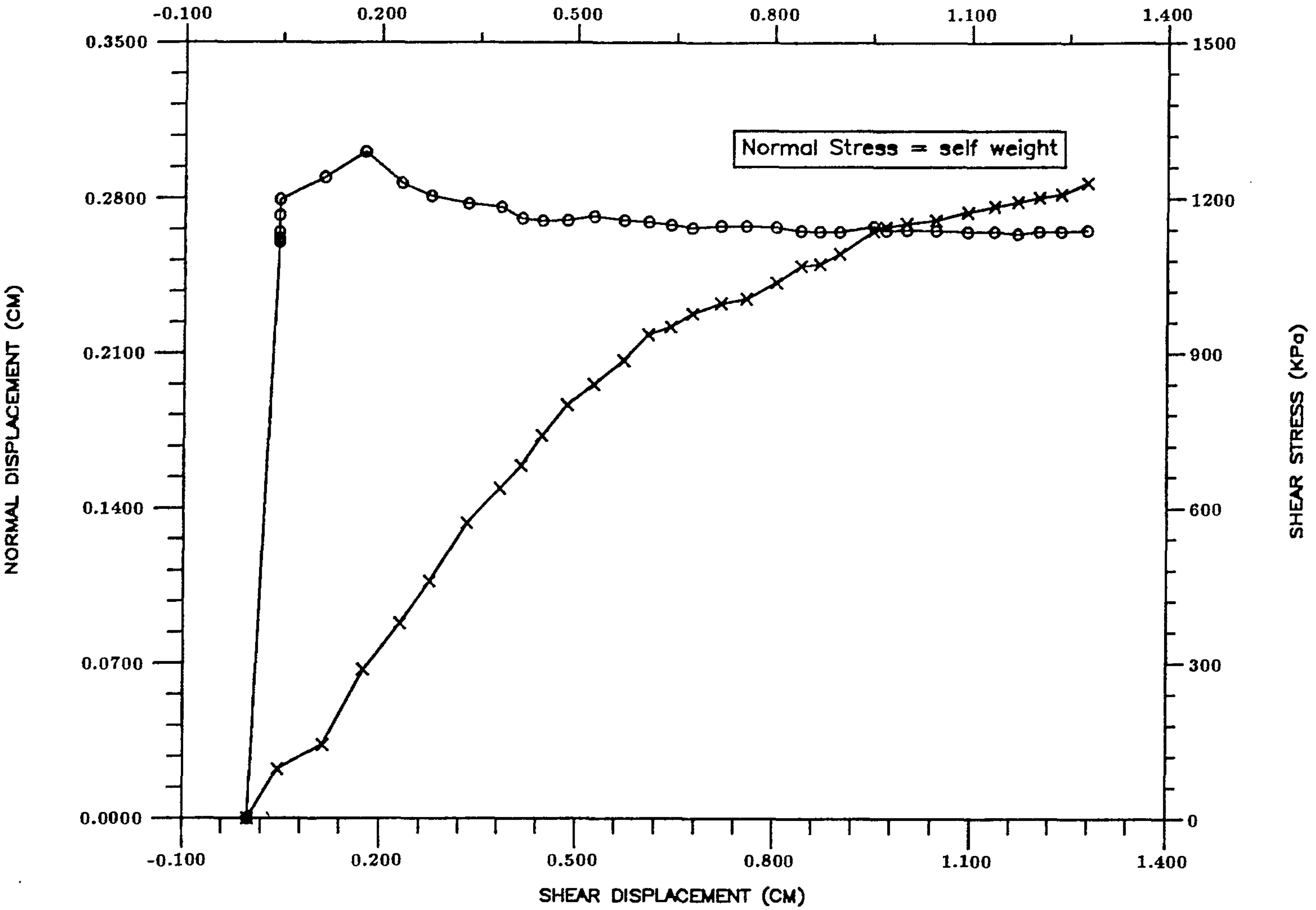

FIG. 3 : Shear test results of Cold Spring Quarry joint specimen no. 4S

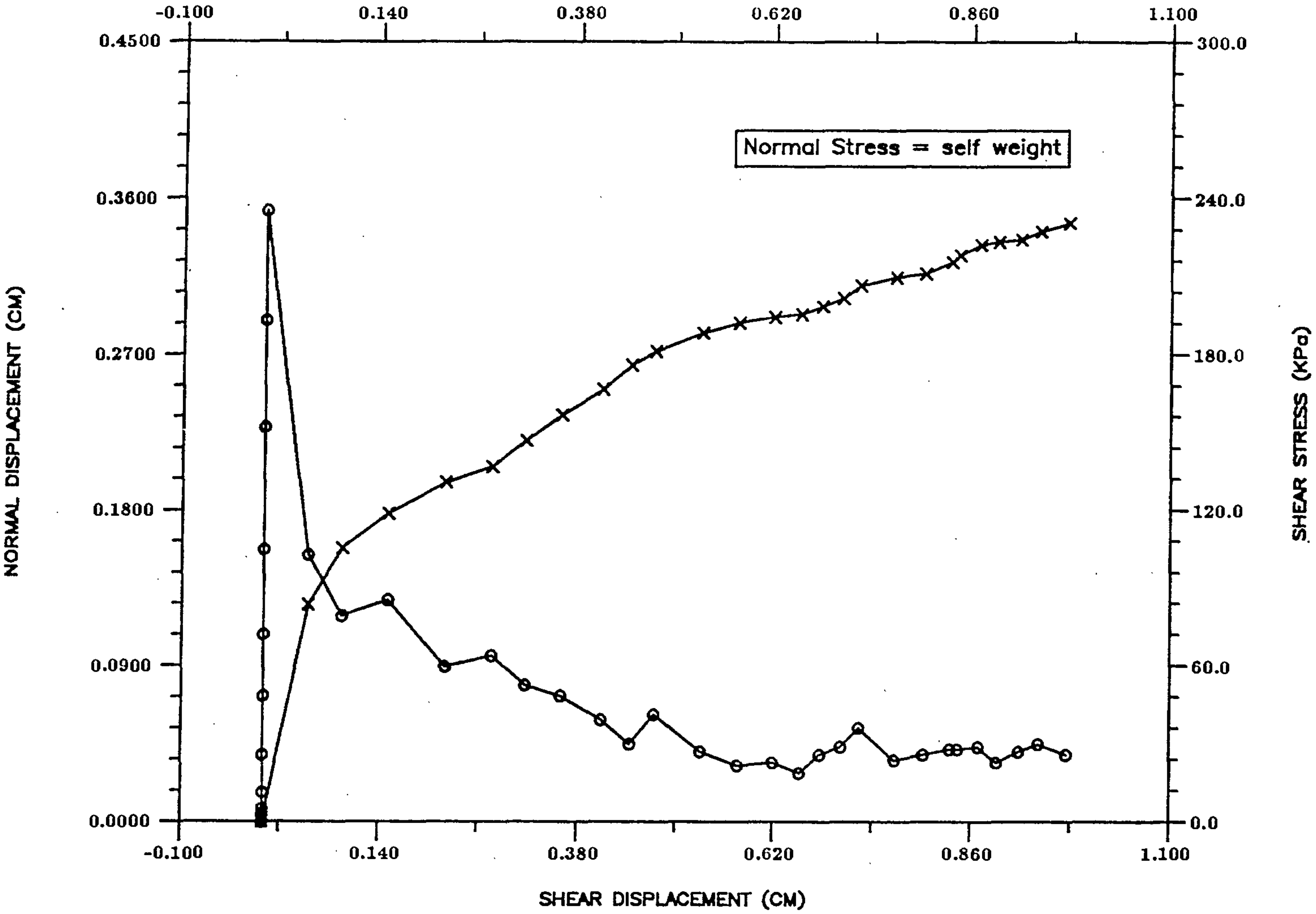

FIG. 4 : Shear test results of Cold Spring Quarry joint specimen no. 5S

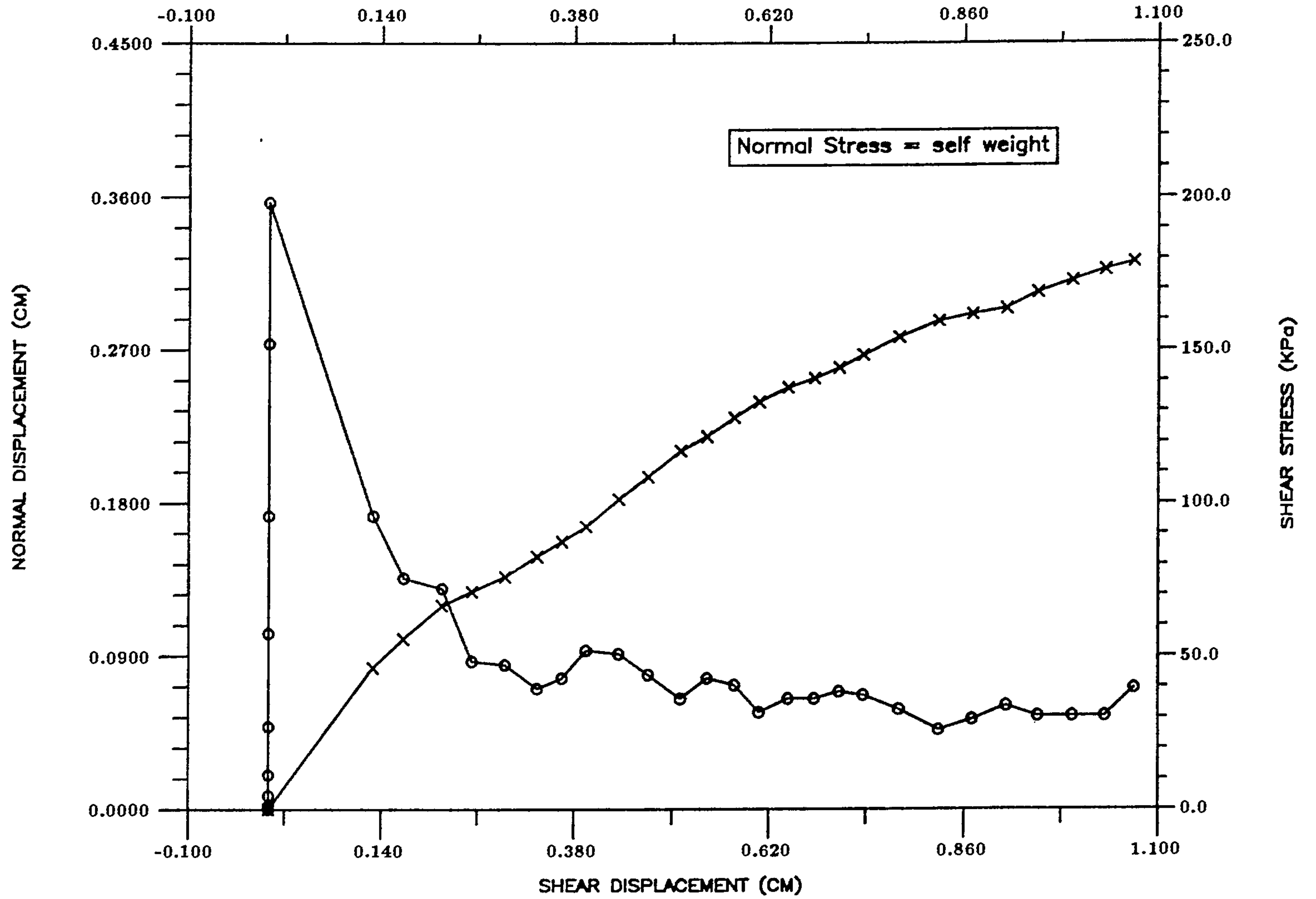

FIG. 5 : Shear test results of Cold Spring Quarry joint specimen no. 7S

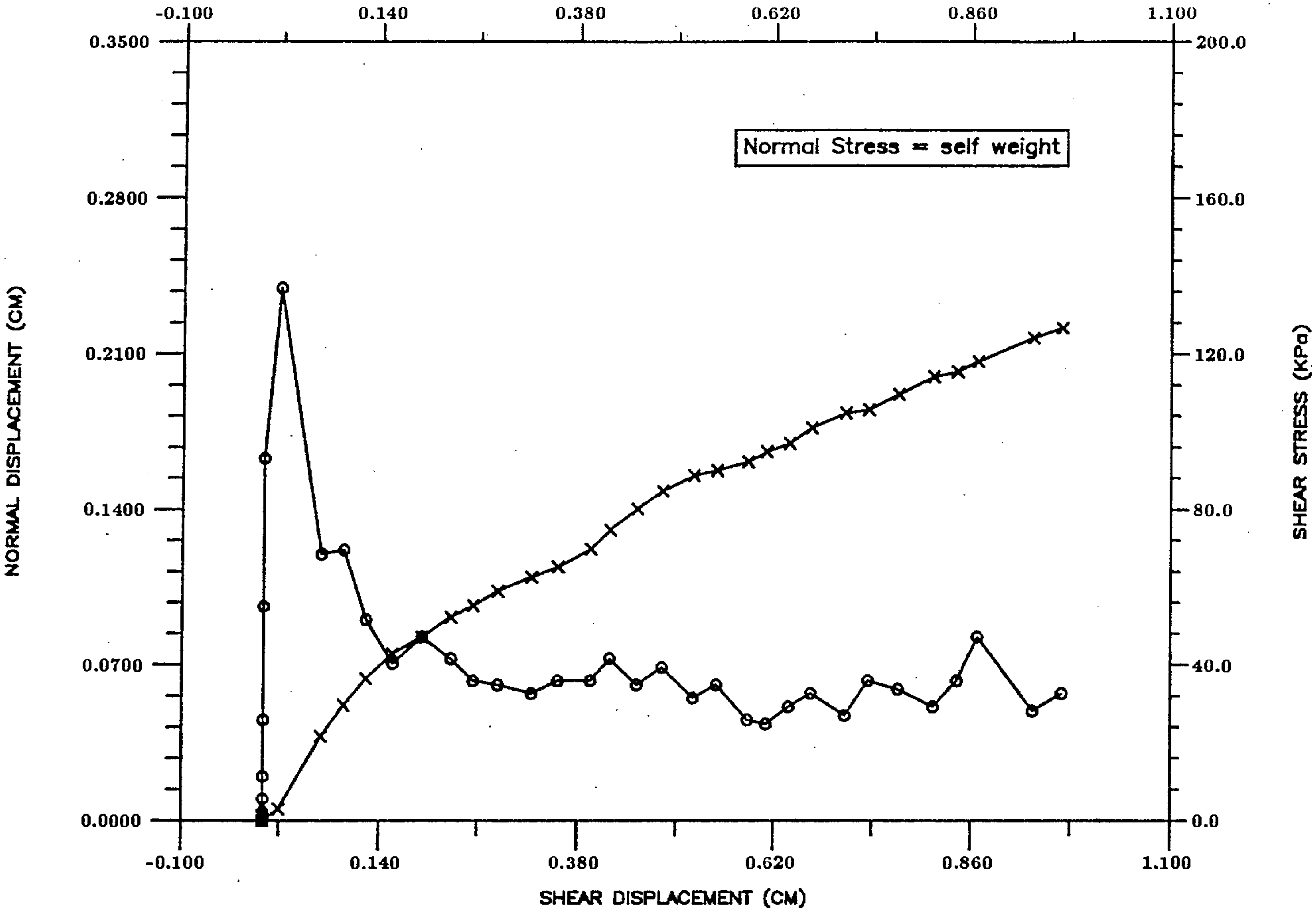

FIG. 6: Shear test results of Cold Spring Quarry joint specimen no. 8S

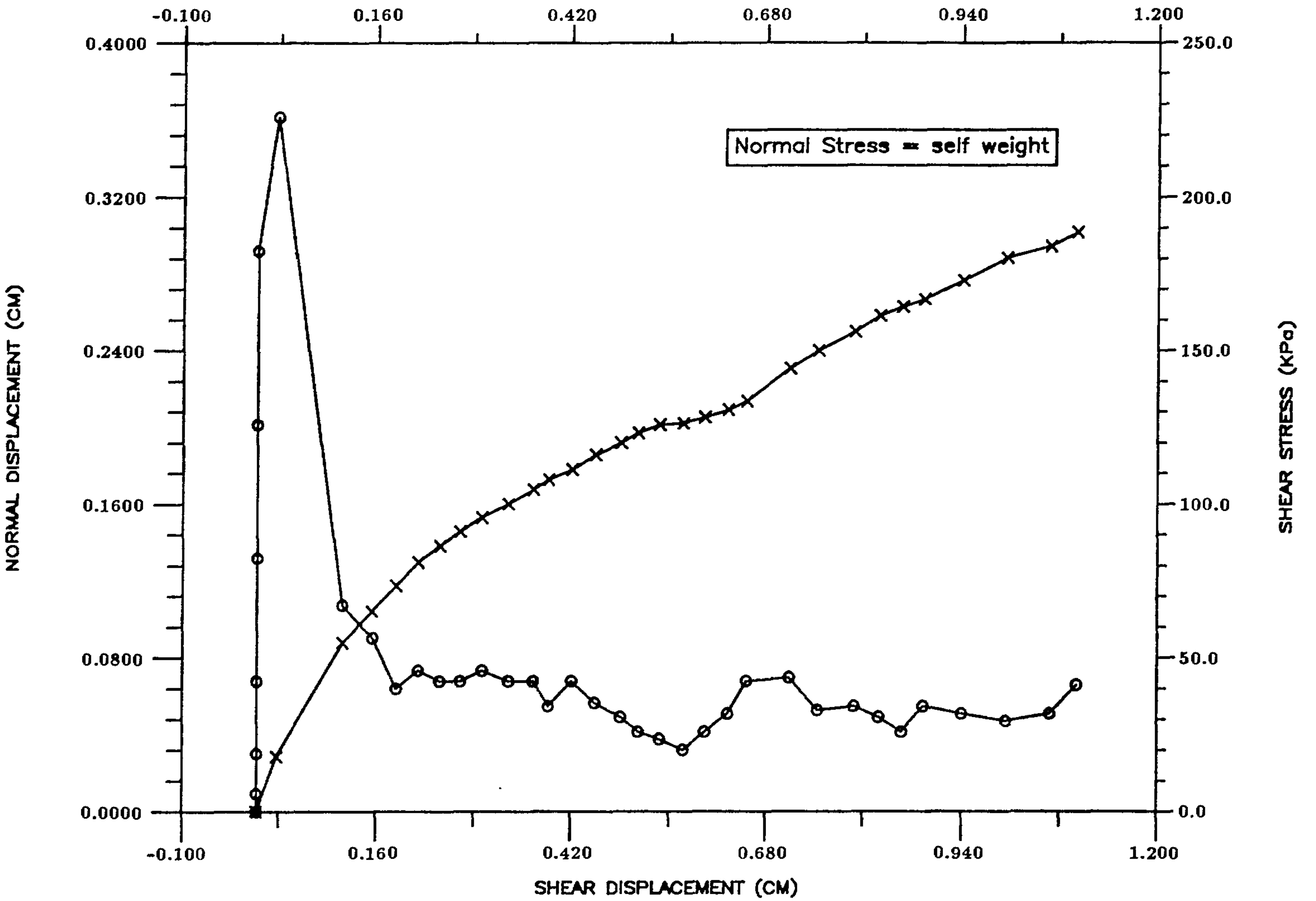

FIG. 7: Shear test results of Cold Spring Quarry joint specimen no. 9S

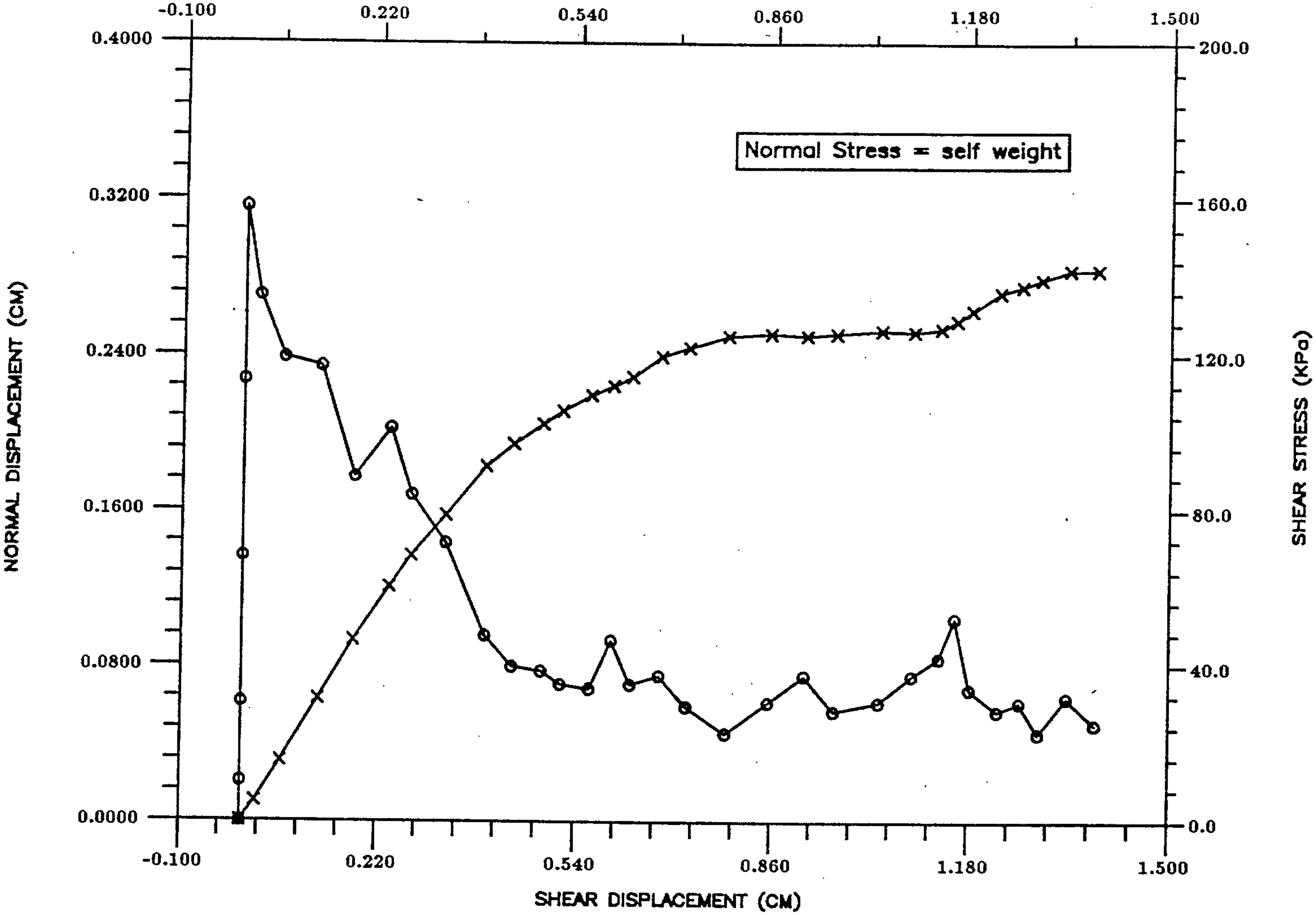

FIG. 8: Shear test results of Cold Spring Quarry joint specimen no. 10S

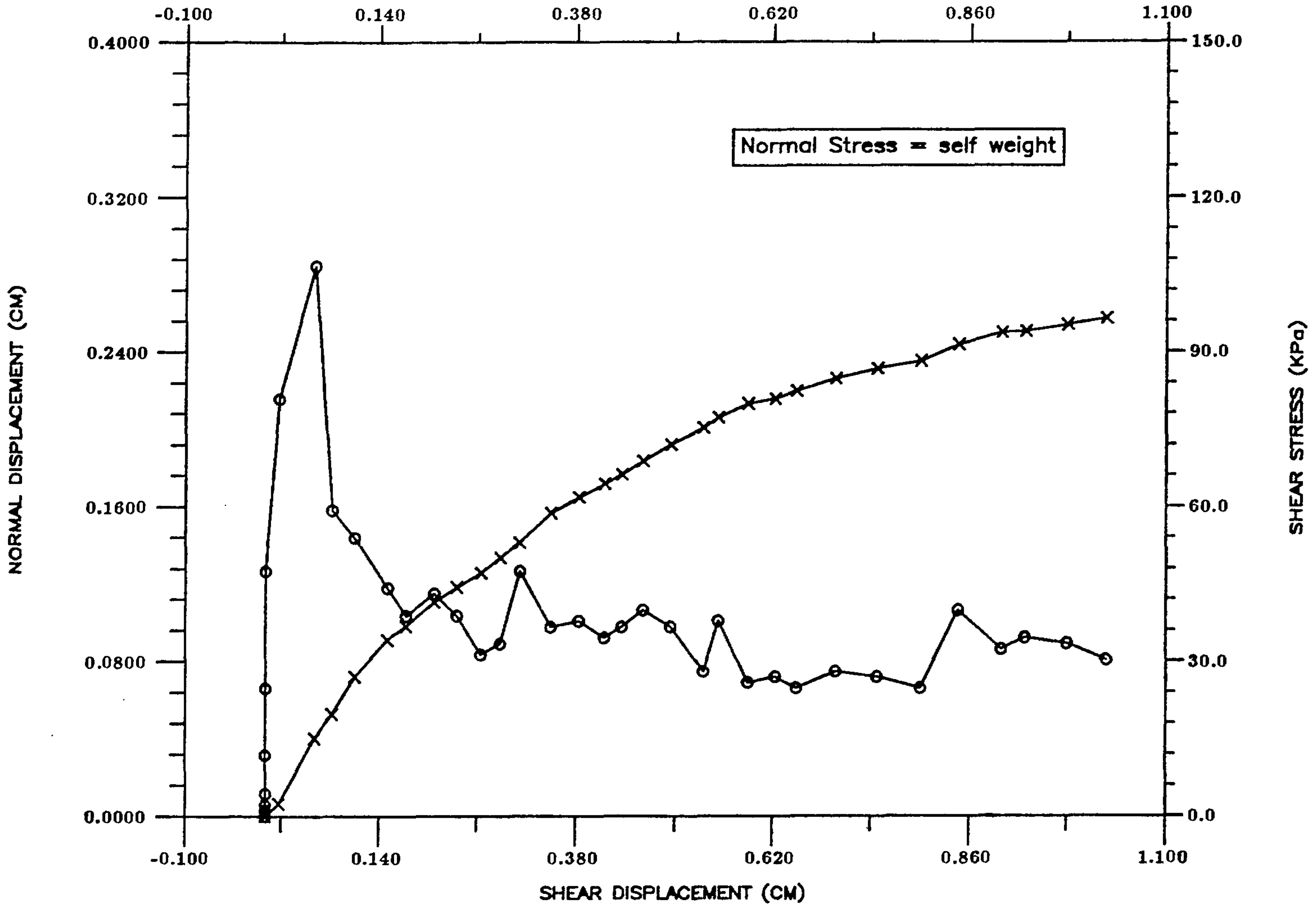

FIG. 9 : Shear test results of Cold Spring Quarry joint specimen no. 11S

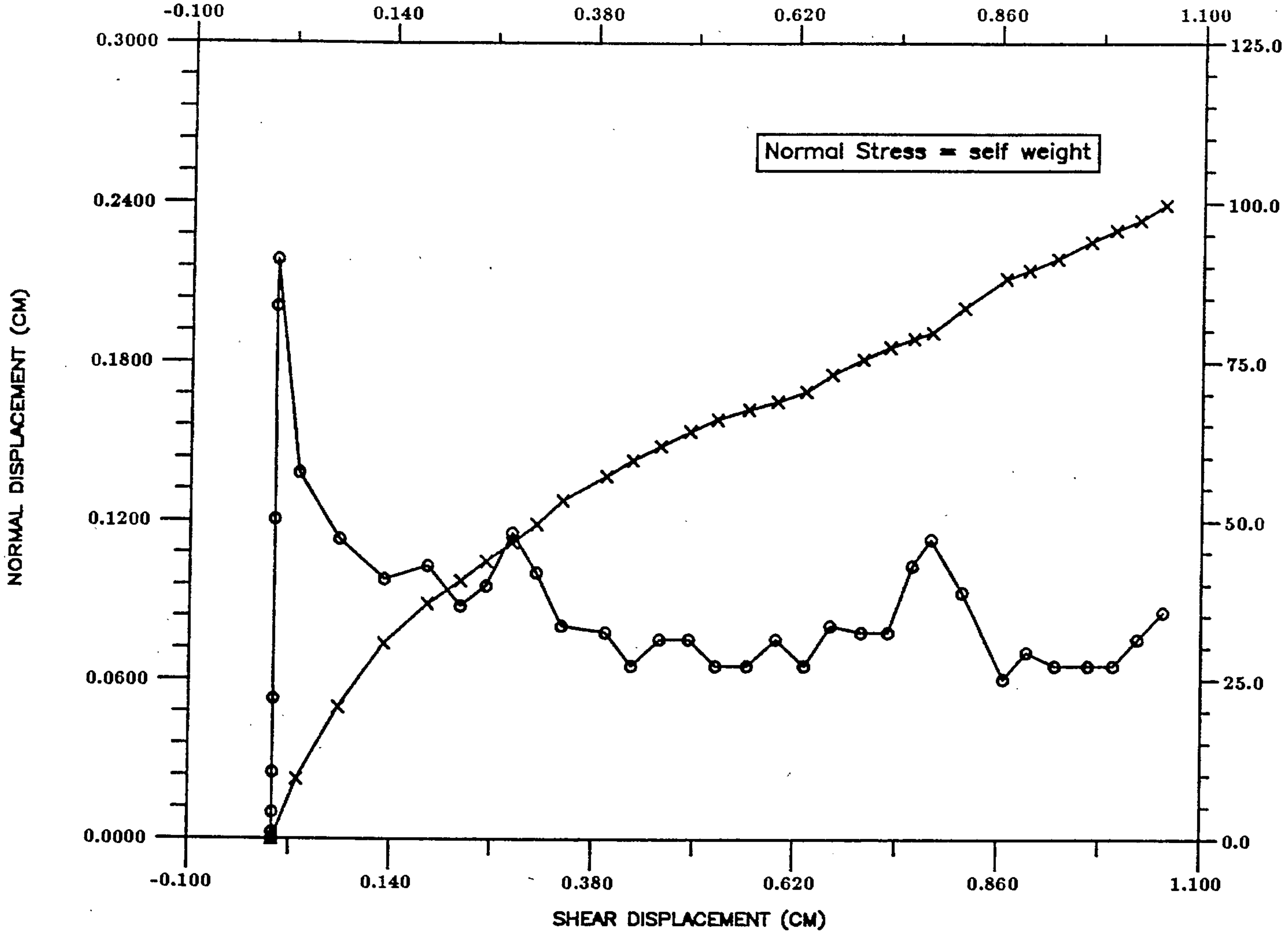

FIG.10: Shear test results of Cold Spring Quarry joint specimen no. 12S

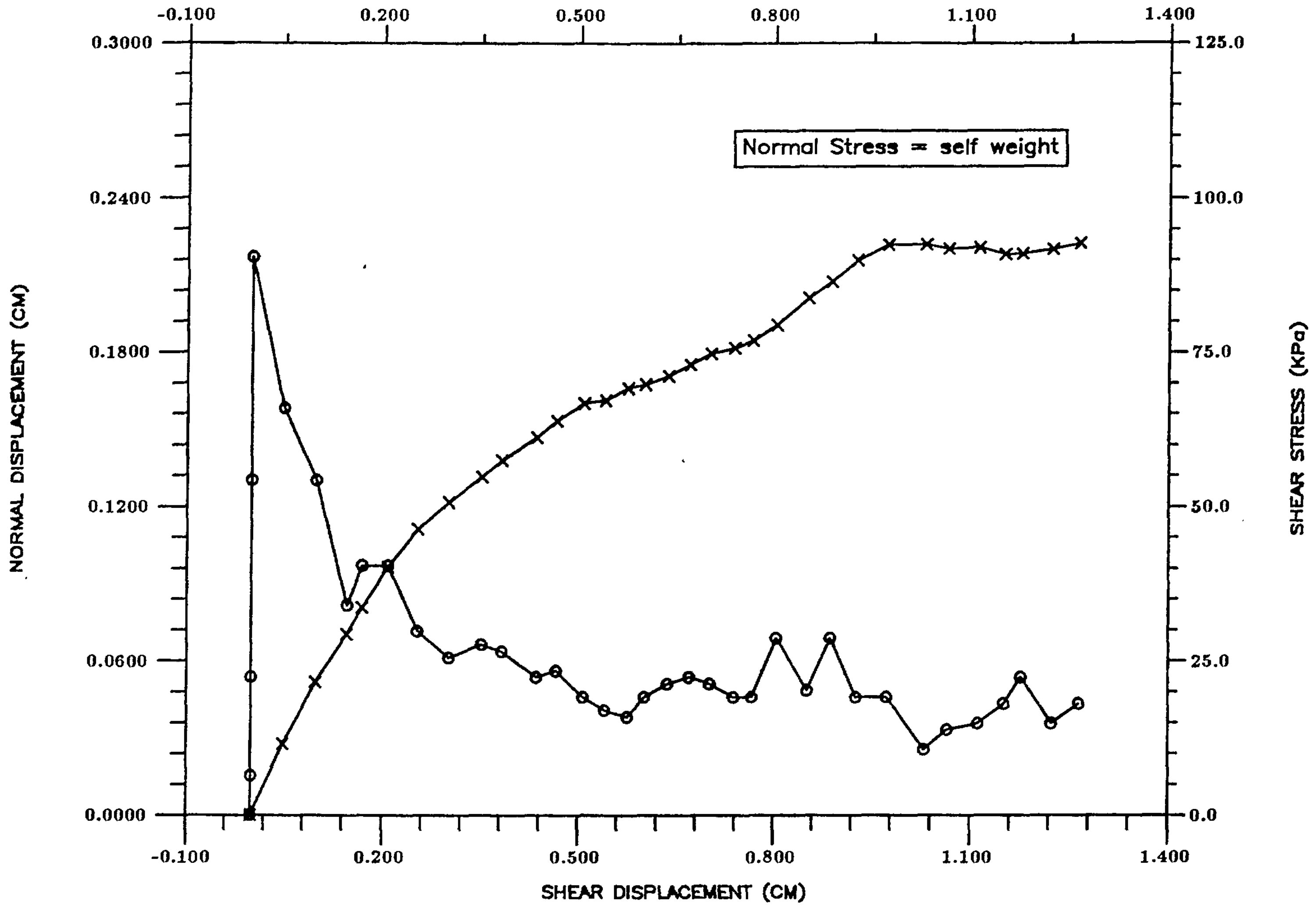

FIG. 11 : Shear test results of Cold Spring Quarry joint specimen no. 13S

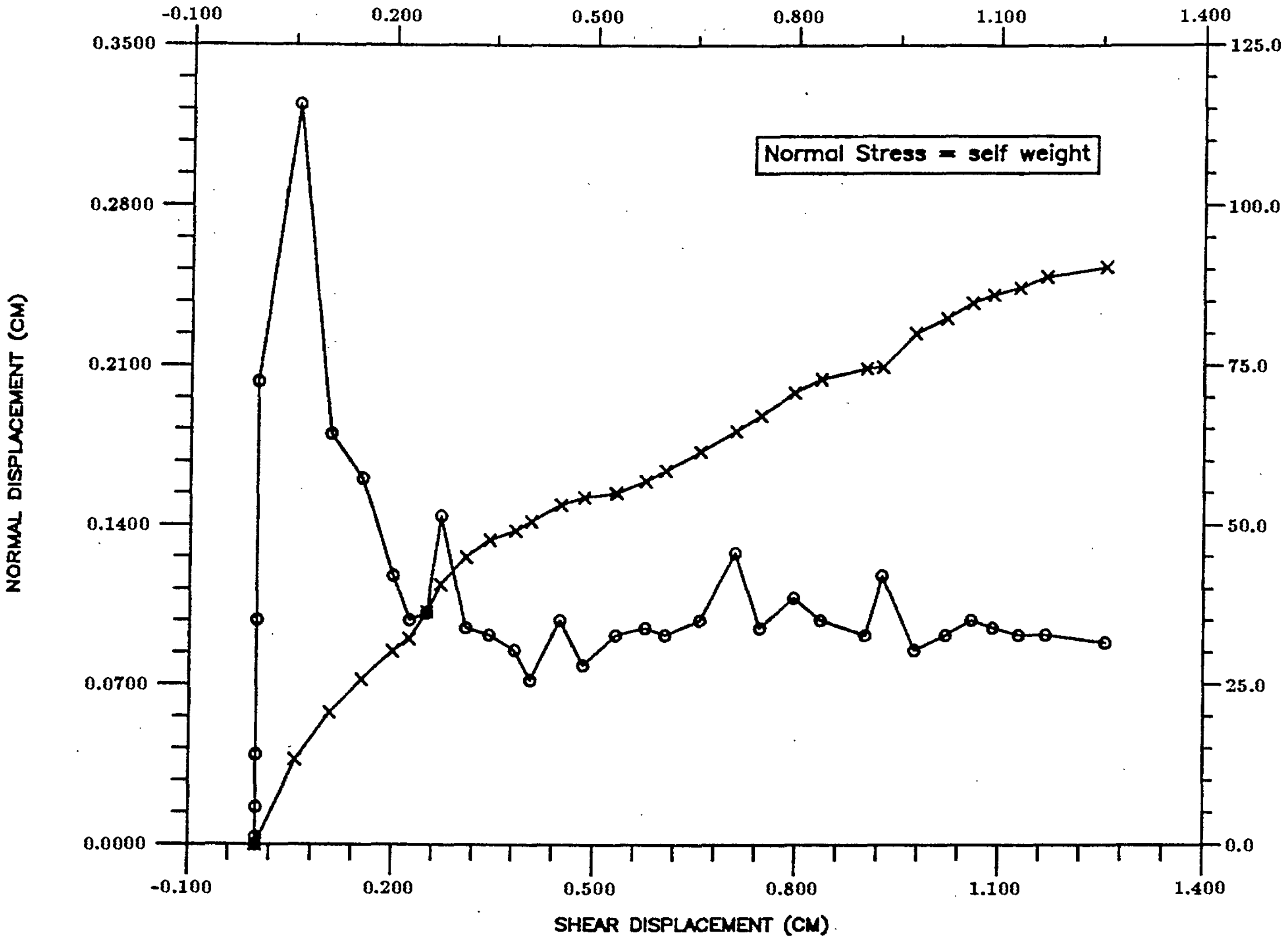

FIG. 12: Shear test results of Cold Spring Quarry joint specimen no. 14S

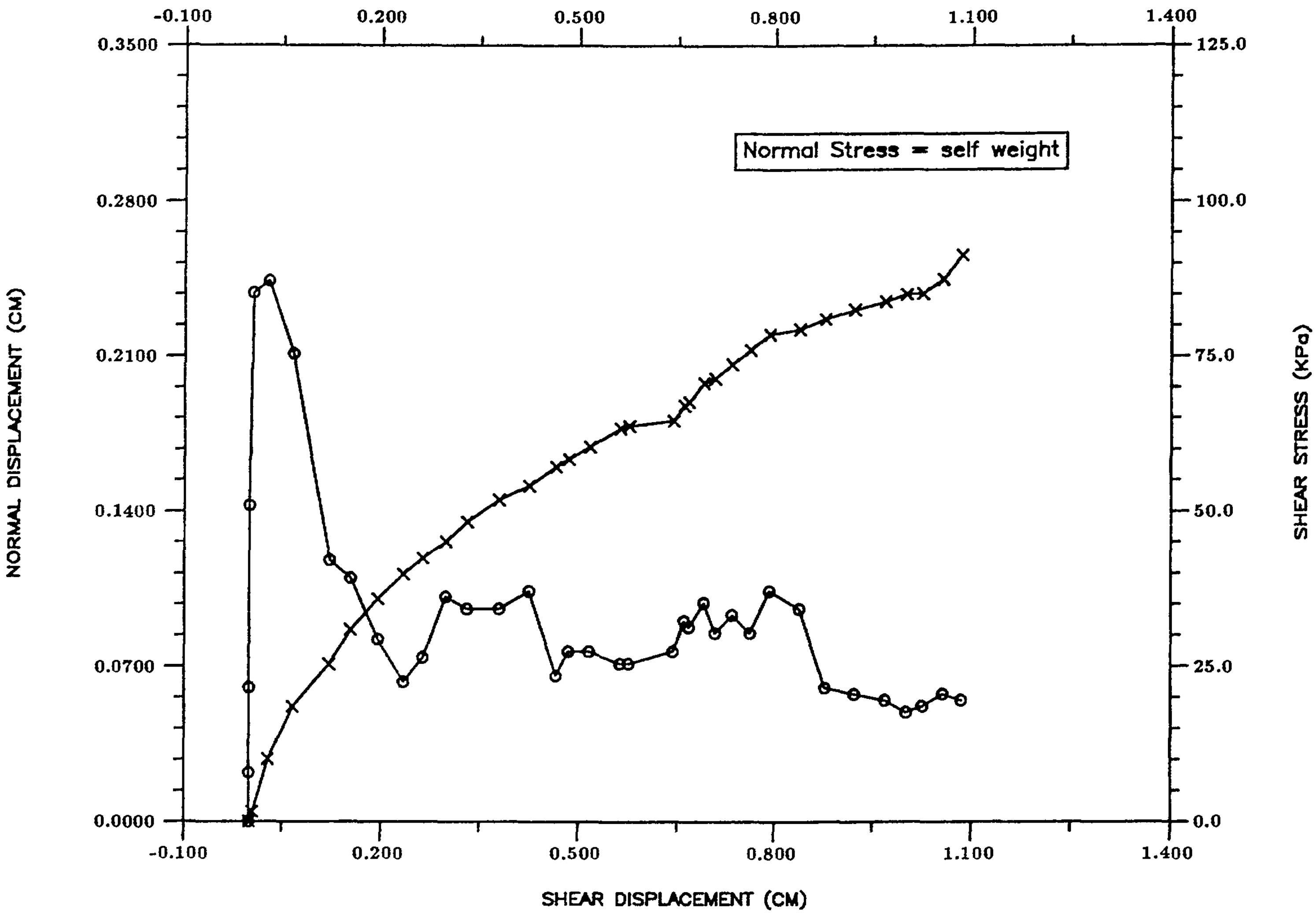

FIG. 13: Shear test results of Cold Spring Quarry joint specimen no. 15S

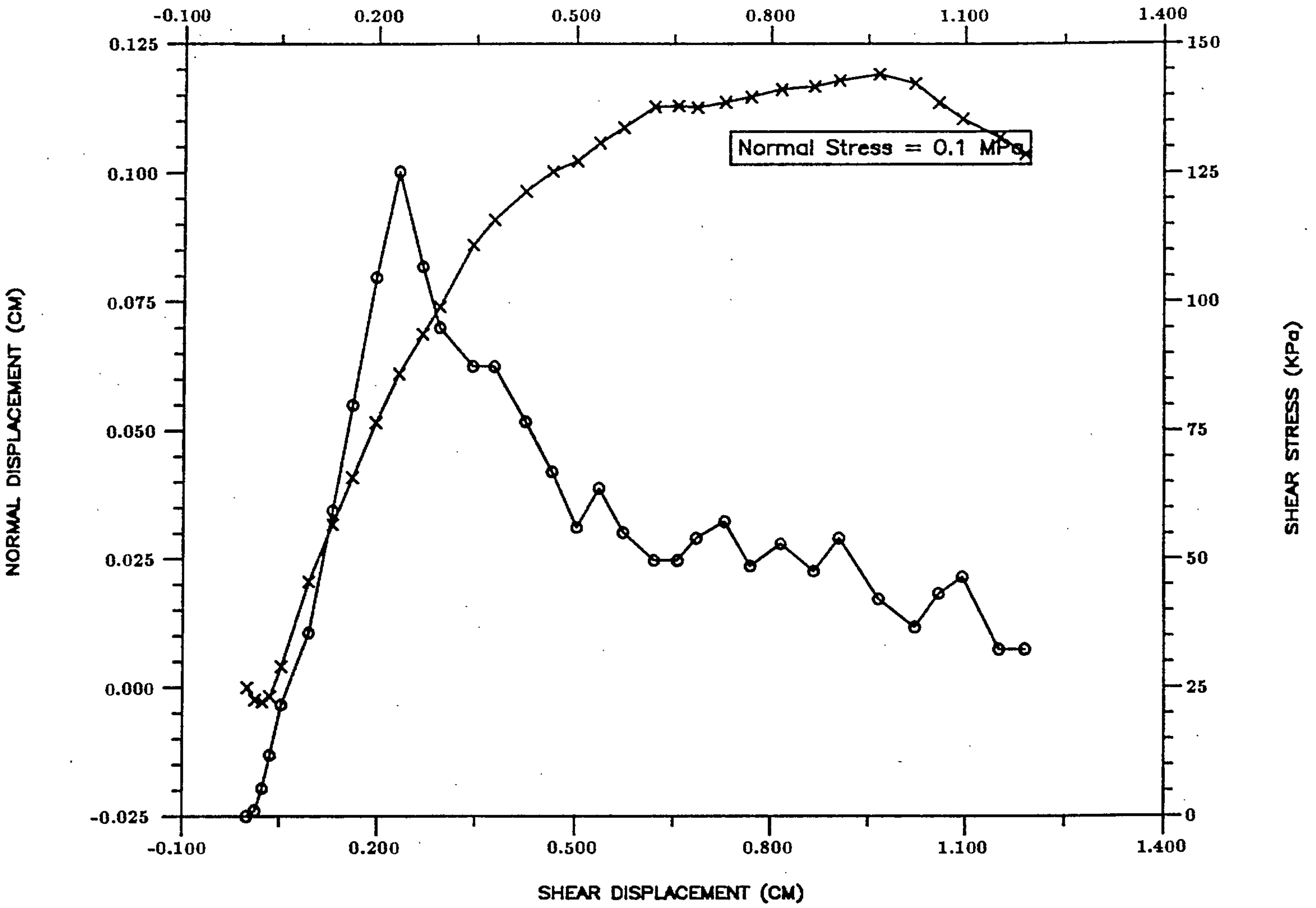

FIG.14: Shear test results of Cold Spring Quarry joint specimen no. 1S

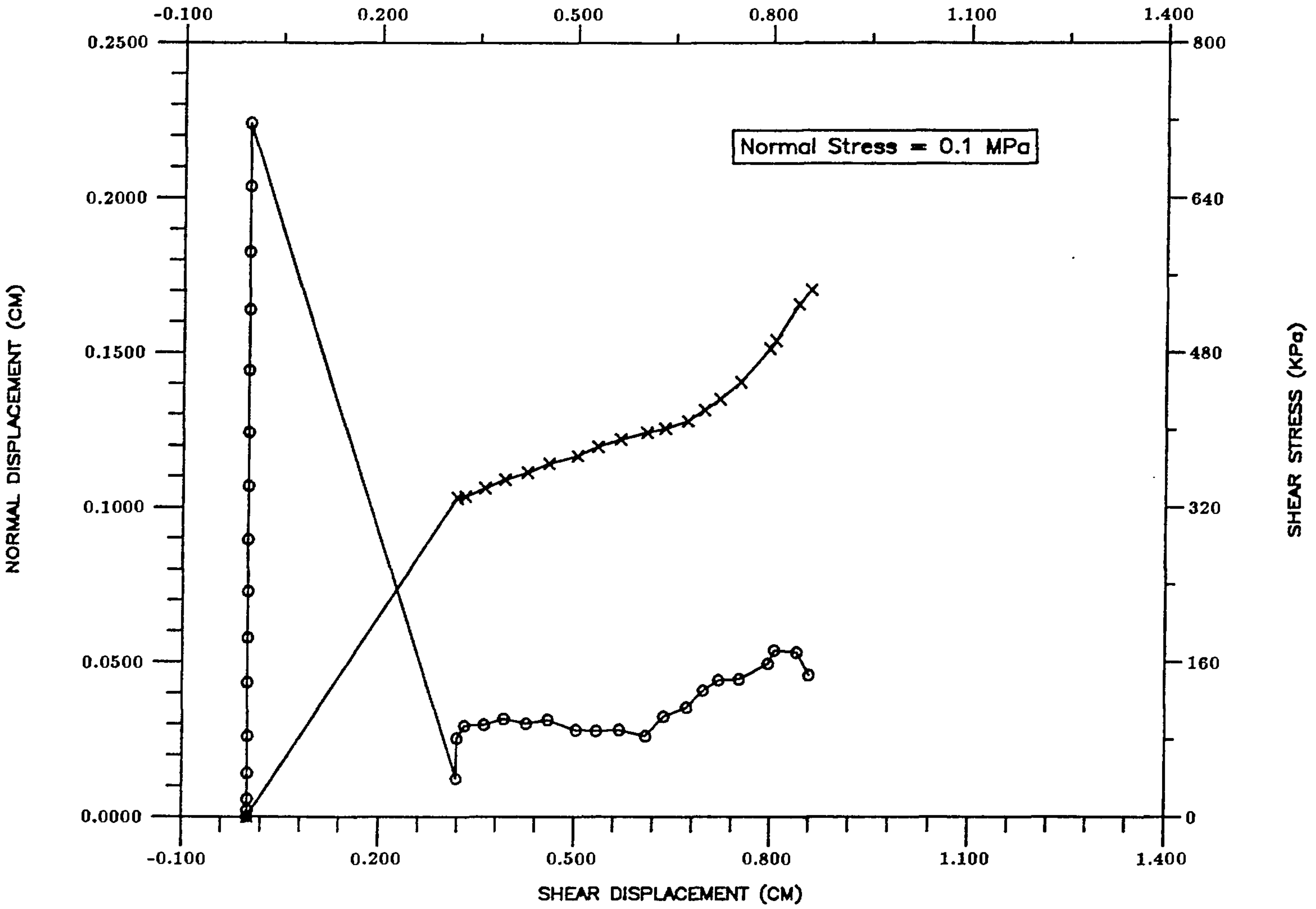

FIG. 15: Shear test results of Cold Spring Quarry joint specimen no. 3S

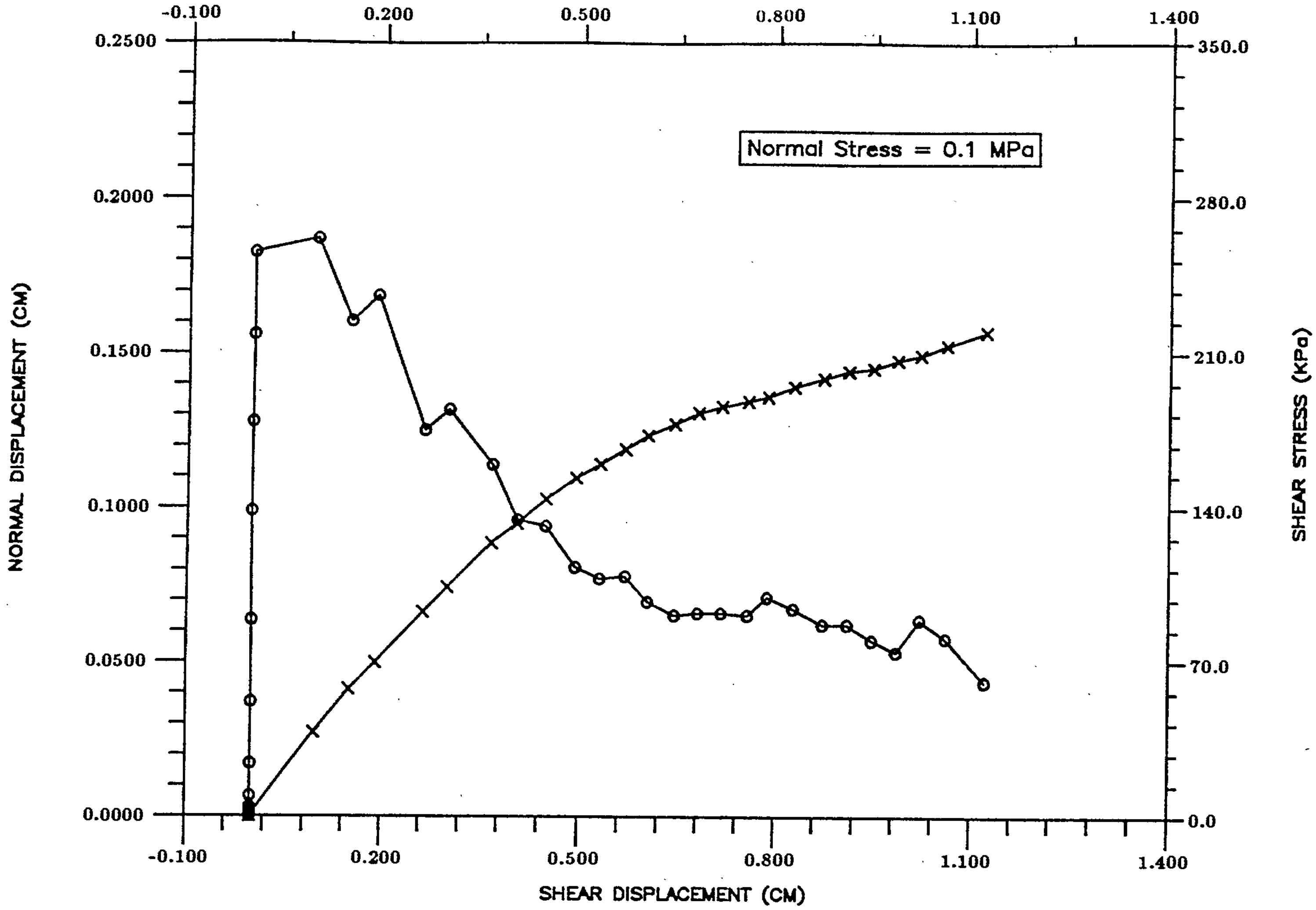

FIG. 16: Shear test results of Cold Spring Quarry joint specimen no. 4S

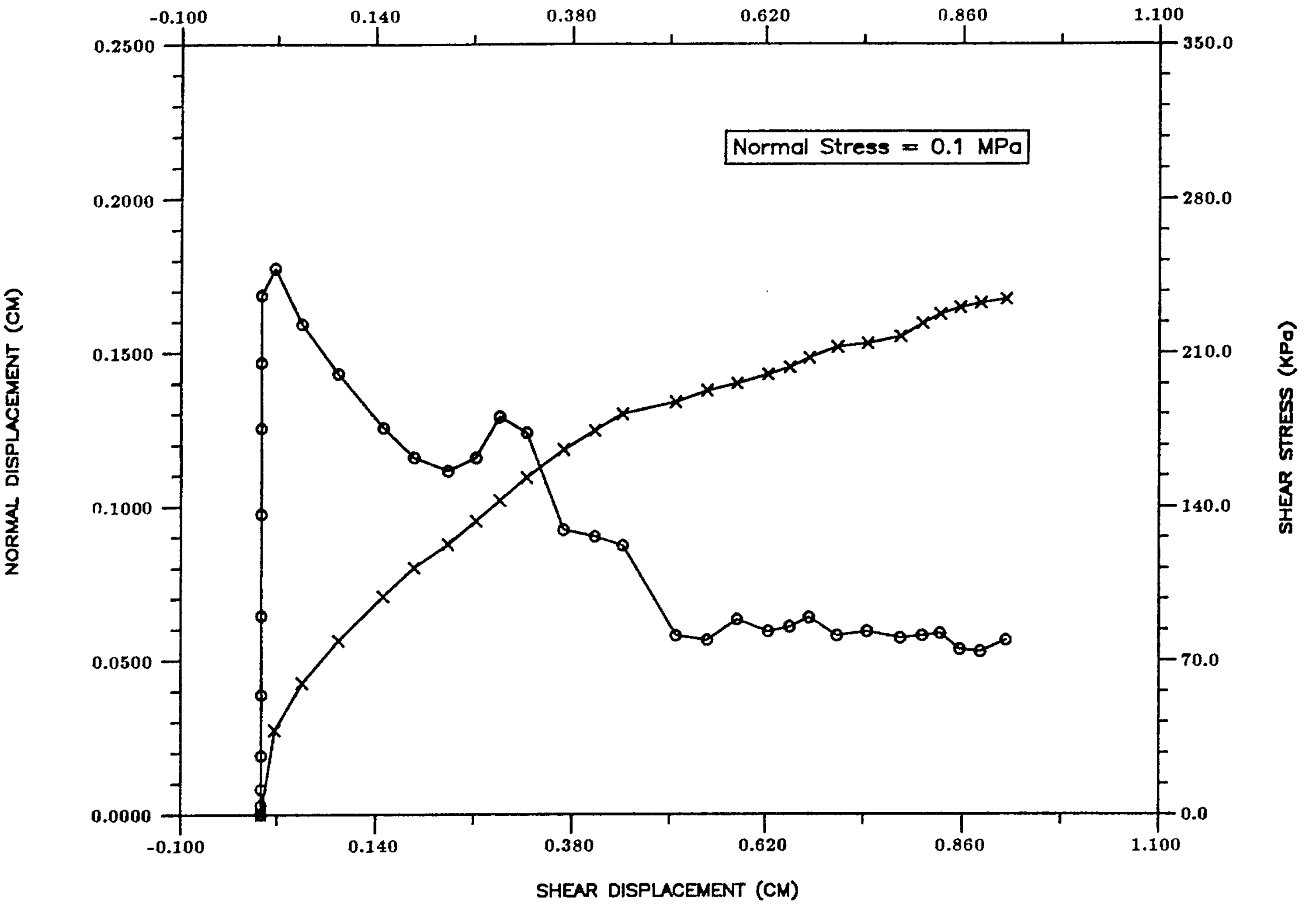

FIG. 17: Shear test results of Cold Spring Quarry joint specimen no. 5S

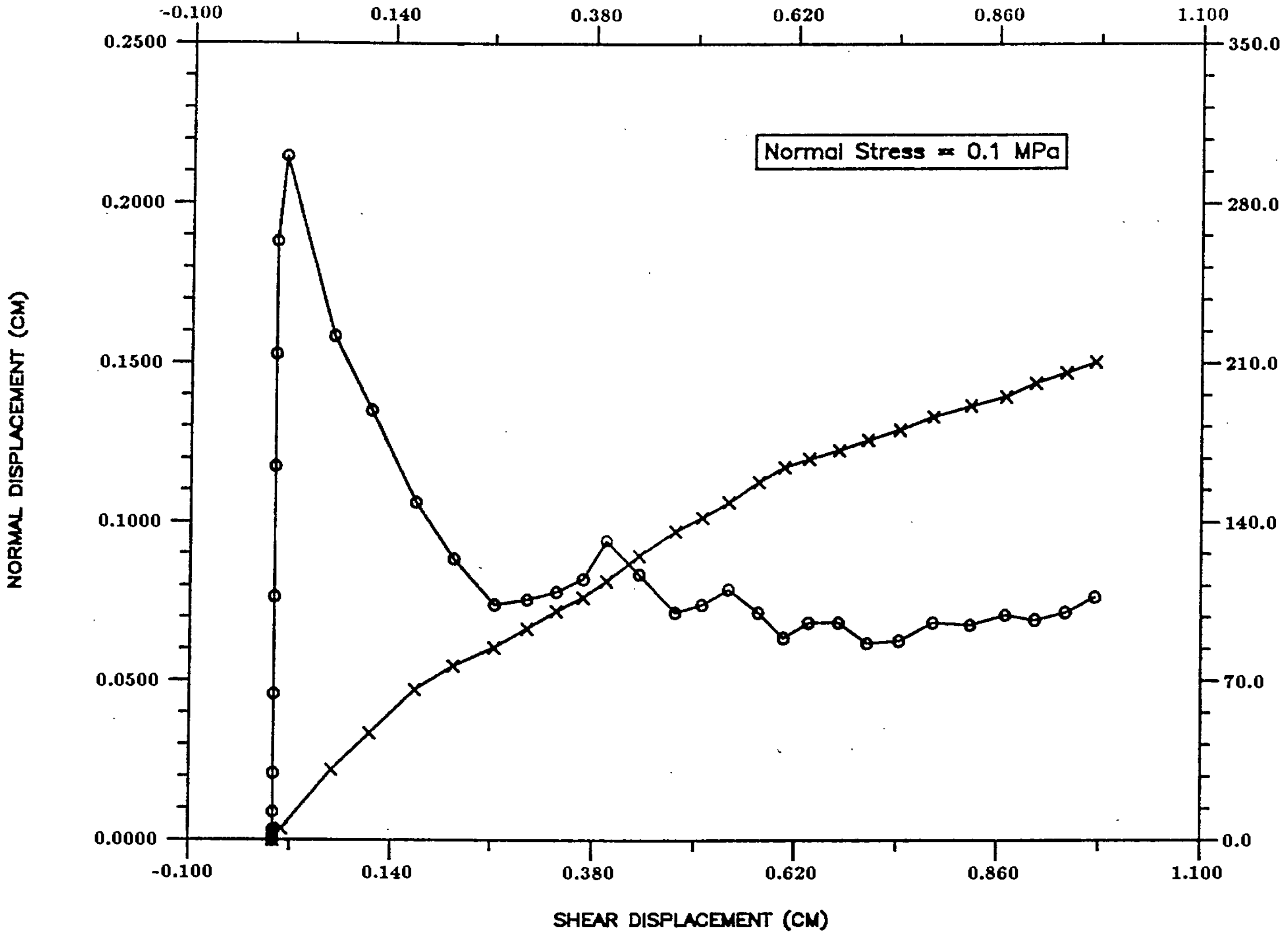

FIG. 18: Shear test results of Cold Spring Quarry joint specimen no. 7S

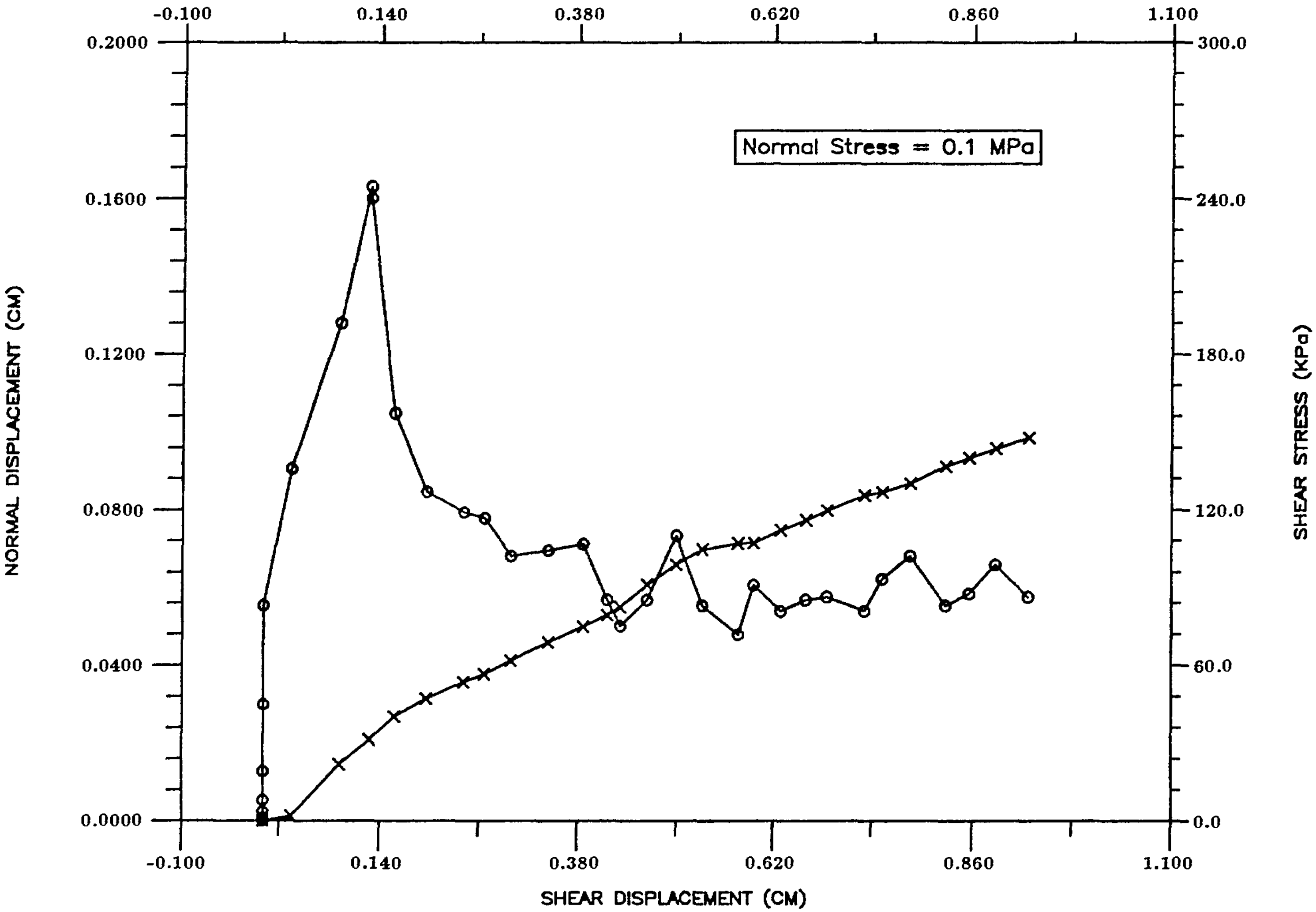

FIG. 19: Shear test results of Cold Spring Quarry joint specimen no. 8S

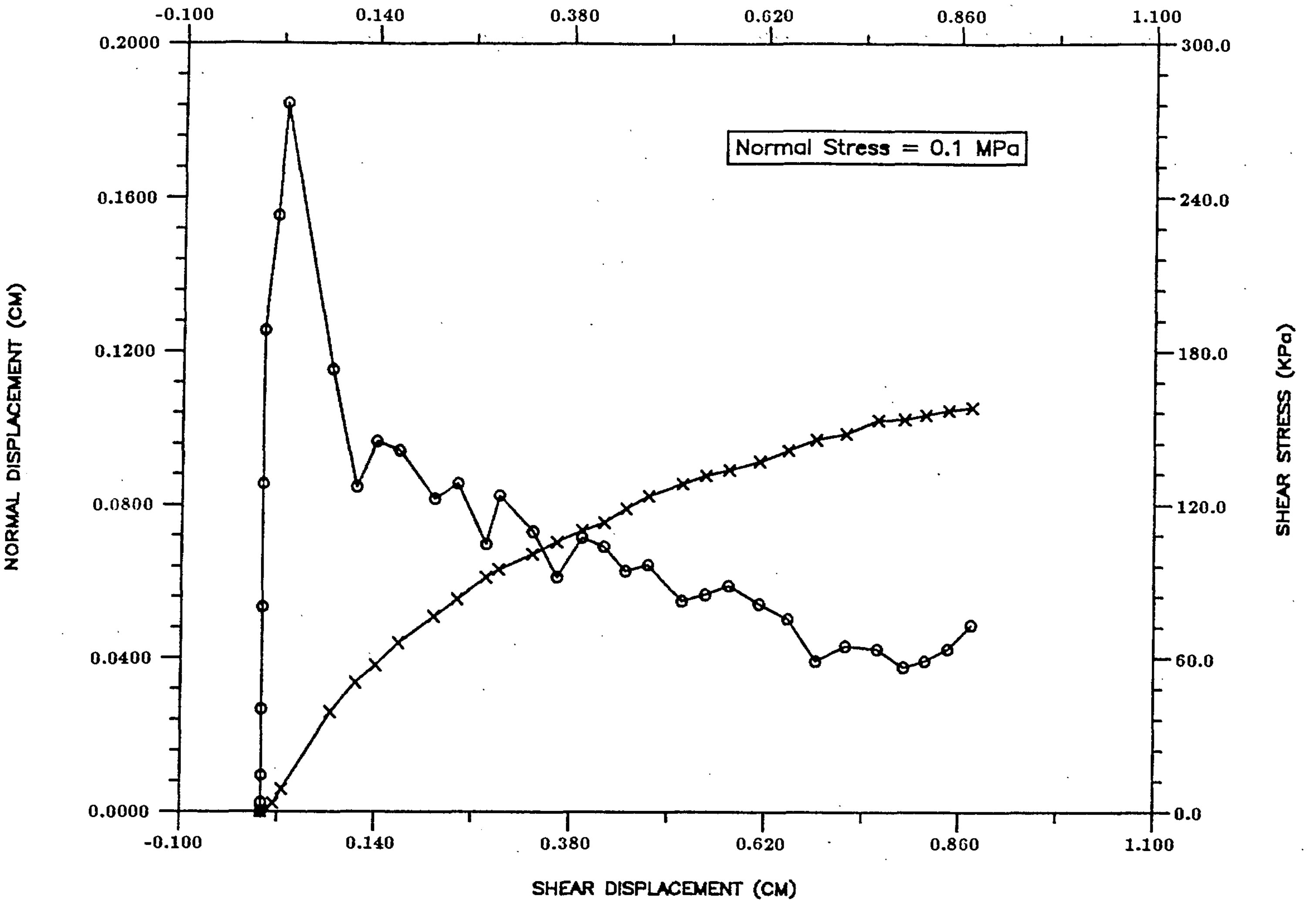

FIG.20: Shear test results of Cold Spring Quarry joint specimen no. 9S

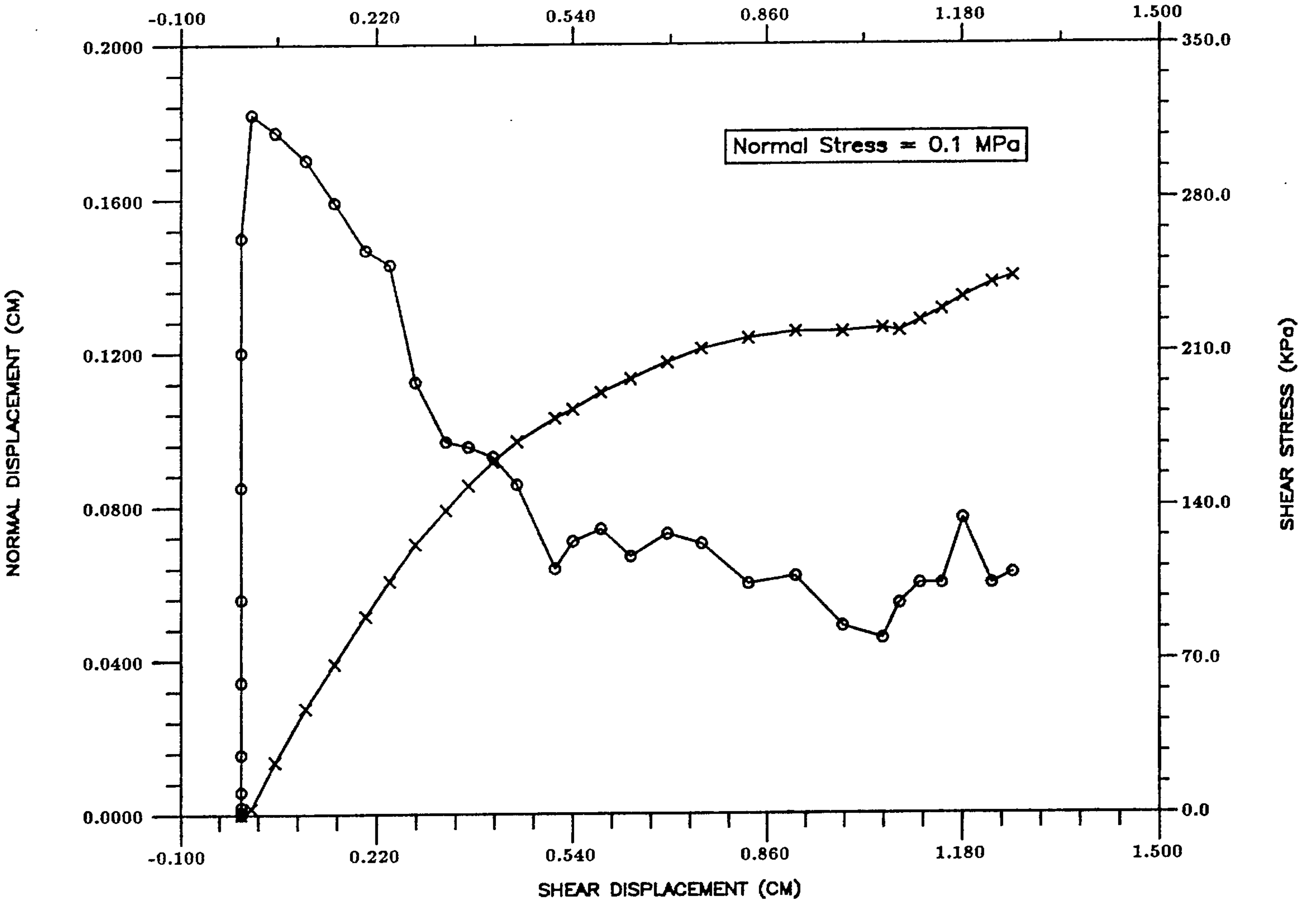

FIG. 21: Shear test results of Cold Spring Quarry joint specimen no. 10S

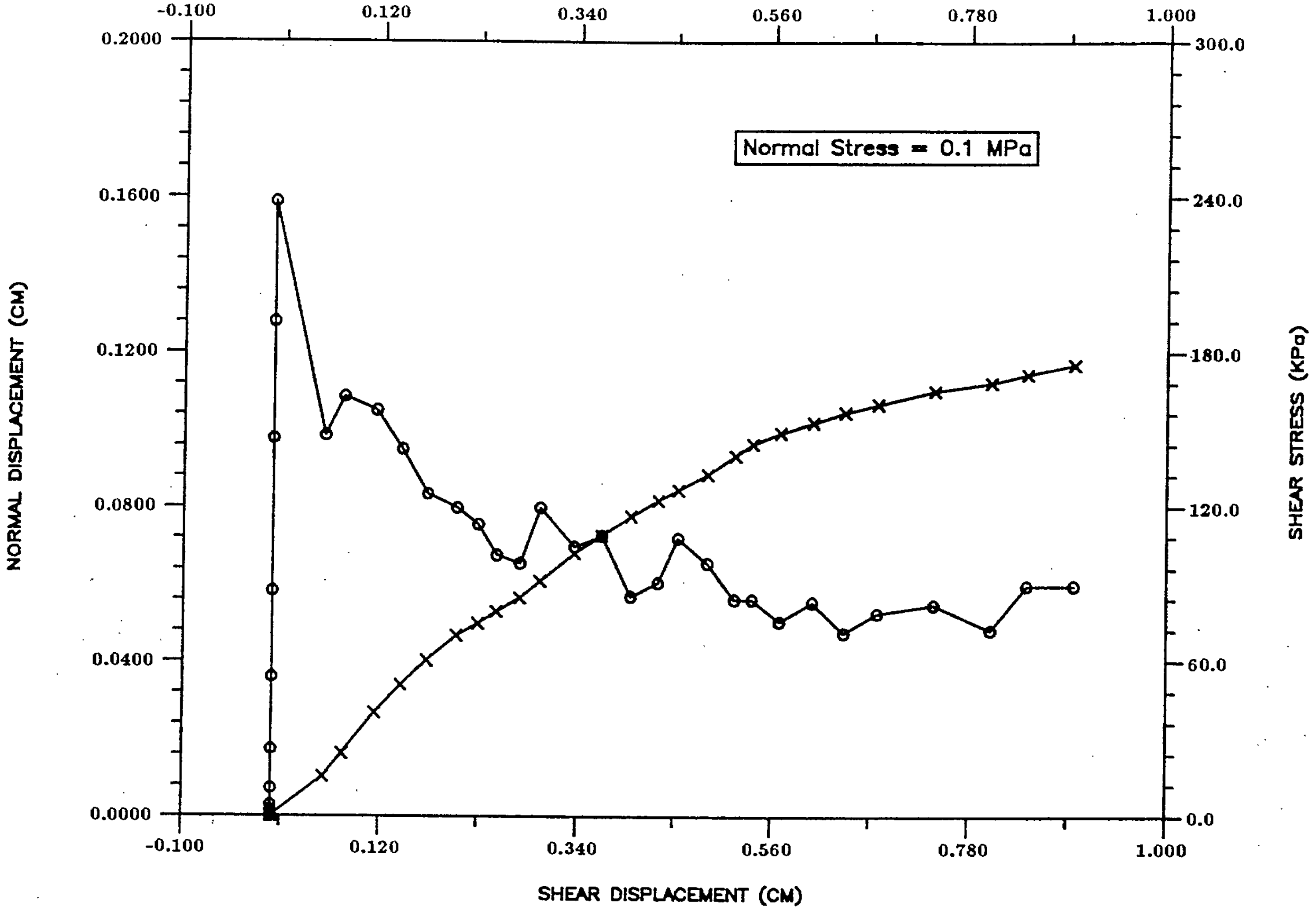

FIG.22: Shear test results of Cold Spring Quarry joint specimen no. 11S

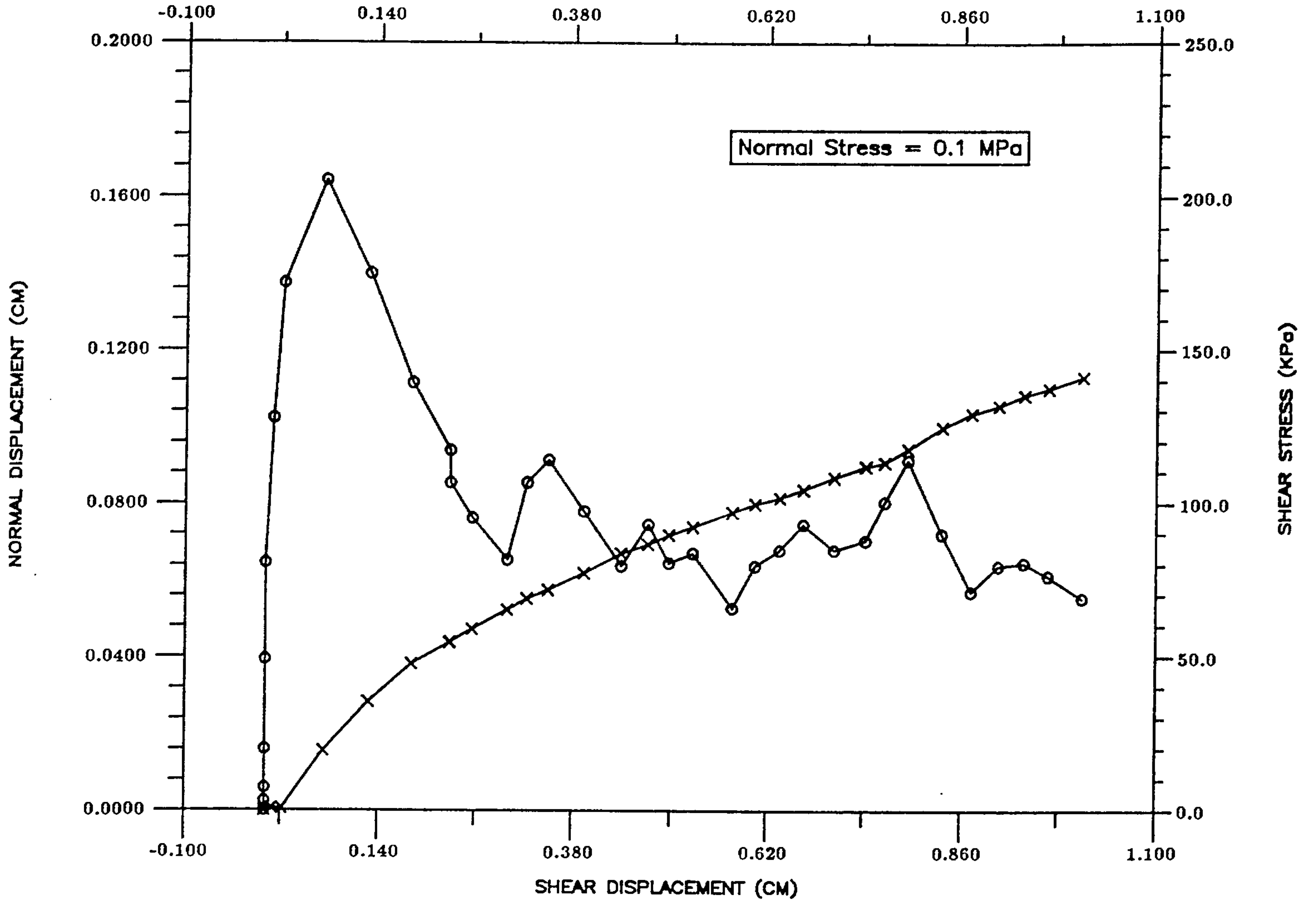

FIG. 23: Shear test results of Cold Spring Quarry joint specimen no. 12S

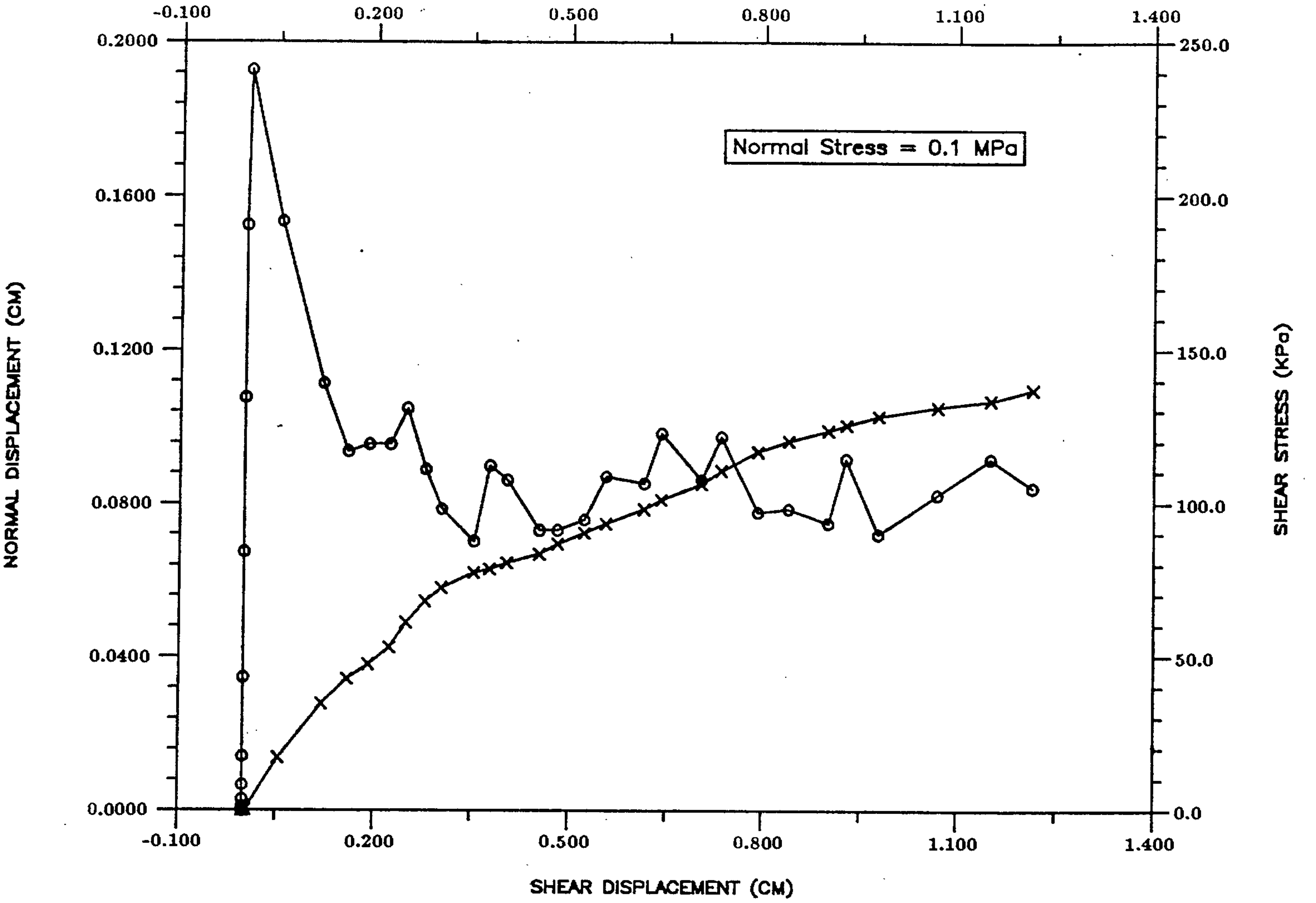

FIG. 25: Shear test results of Cold Spring Quarry joint specimen no. 14S

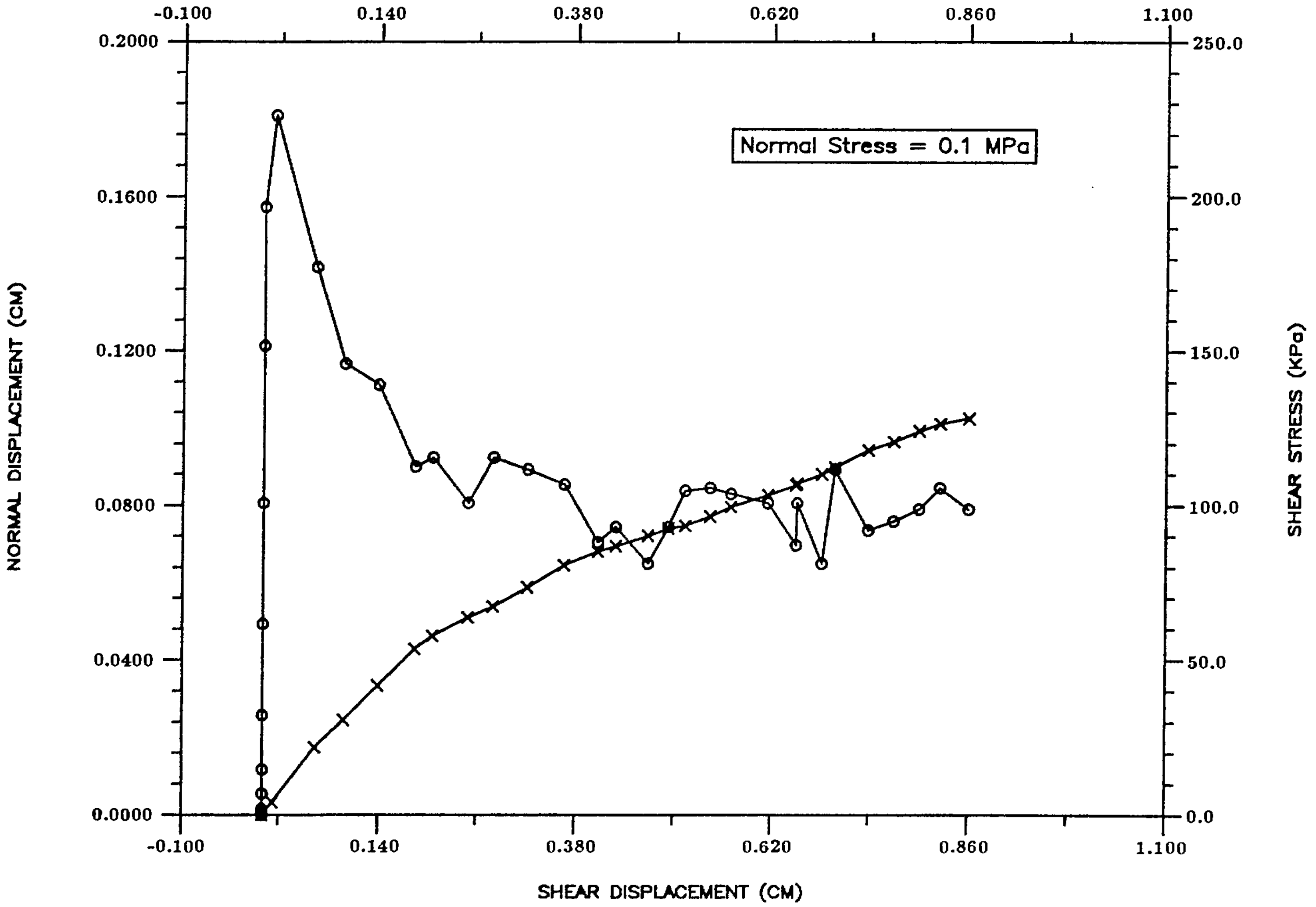

FIG. 26: Shear test results of Cold Spring Quarry joint specimen no. 15S

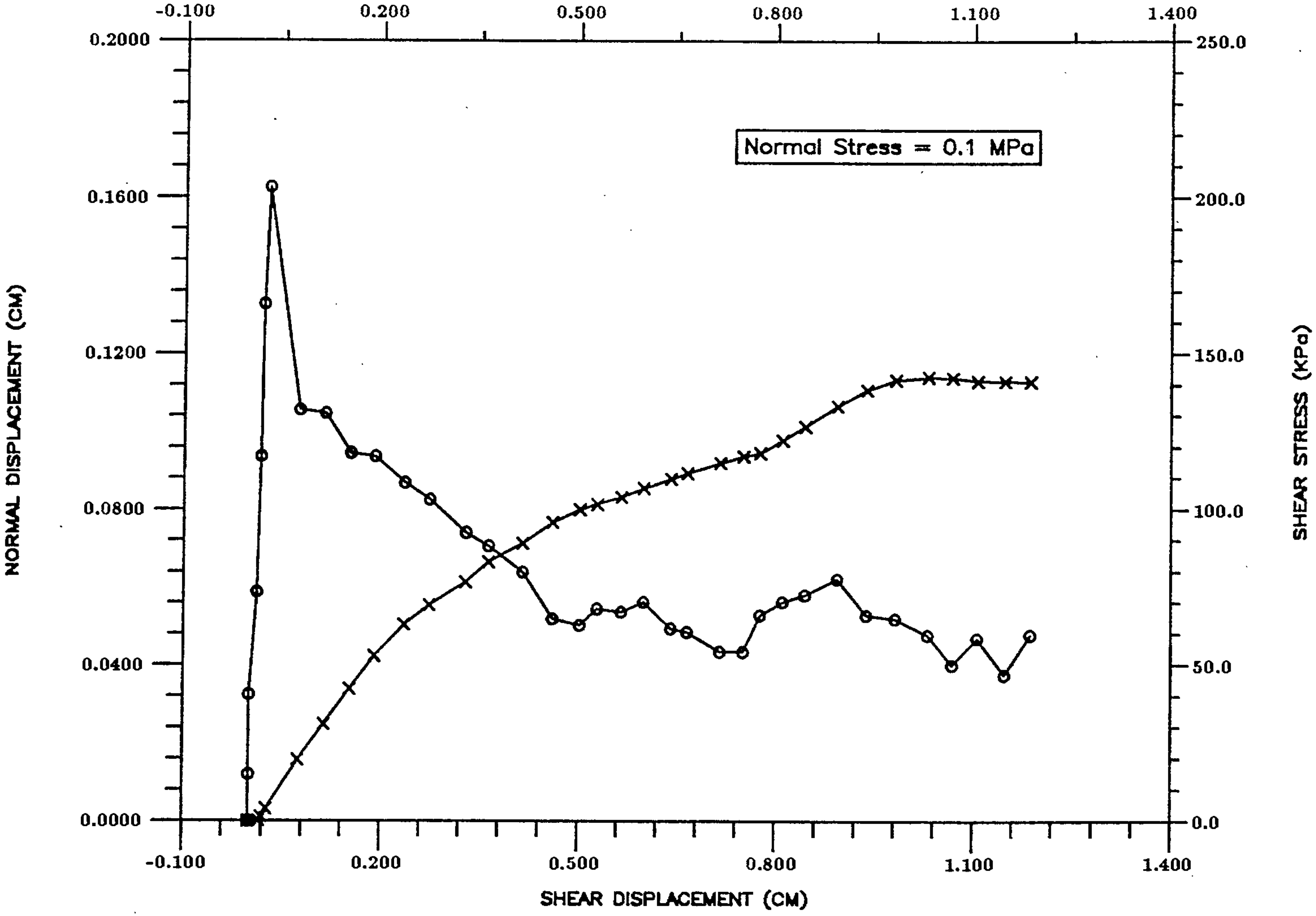

FIG. 24: Shear test results of Cold Spring Quarry joint specimen no. 13S