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POST-FAILURE UNIAXIAL TESTING ON URL1 CORE

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JUNE 1987

23 pp

MINING RESEARCH LABORATORIES
DIVISION REPORT MRL 87-80(TR)

1-7994065

POST–FAILURE UNIAXIAL TESTING ON URL1 CORE

by

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ABSTRACT

Post-failure testing of rock has received considerable interest recently and was the subject of a test program used during the start up of the Canadian Mine Technology Laboratory's new rock mechanics test system. Eleven samples obtained from the Lac du Bonnet batholith near Atomic Energy of Canada Ltd.'s Underground Research Laboratory site were tested.

The slower loading rate required for the testing technique described here has resulted in a lower mean uniaxial strength than that determined previously for samples tested from the same area. Little change, however, was noted in the values of the modulus of elasticity and Poisson's ratio.

The test system performed according to expectations but it is suggested that an auxilliary, lower capacity load frame be purchased to enable faster actuator response.

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Keywords

Post-failure, Rock Properties, Mechanical, Young's Modulus, Poisson's Ratio, Uniaxial Compressive Strength, Lac du Bonnet

ESSAIS DE COMPRESSION UNIAXIALE APRÈS EFFONDREMENT EFFECTUÉS SUR LA CAROTTE URL1

par

Rand Jackson*

RÉSUMÉ

Au cours des dernières années, les essais sur les roches après effondrement ont reçu une attention considérable et ont fait l'objet d'un programme d'essais utilisé lors de la mise en place du nouveau système d'essia sur la mécanique des roches du Laboratoire canadien de technologie minière. On a fait des essais sur onze echantillons prélevés du batholite de Lac du Bonnet, près du Laboratoire de recherches souterraines d'Énergies atomique du Canada Ltée.

La faible vitesse de chargement, nécessaire pour la technique d'essai décrite dans le présent rapport, a donné une résistance moyenne uniaxiale inférieure à celle qui avait été déterminée précédemment lors d'essais sur des échantillons provenant de la même région. On a toutefois noté peu de changements dans les valeurs du module d'élasticité et du coefficient de Poisson.

Le système d'essia fonctionnait selon les prévisions, mais on a suggéré d'acheter une presse hydraulique auxiliaire à rendement inférieur afin d'accélérer la réponse de mise en action.

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Mots – clés

après effondrement, propriétés des roches, mécanique, module de Young, coefficient de Poisson, résistance à la compression uniaxiale, Lac du Bonnet.

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INTRODUCTION

Of late, there has been increased interest in the post-failure behaviour of rock and how it relates to the long term stability of underground openings. Testing in the post-failure region has historically been conducted using very stiff testing machines which minimized the transfer of stored strain energy from the load frame to the the specimen at the point of failure. While the entire stress/strain curve is then readily obtained for Class 1 rocks where axial strain increases monotonically throughout the loading cycle, it is not so easily achieved for borderline Class 1/Class 2 and Class 2 rocks. The nature of Class 2 rock requires that energy be extracted from the sample at ultimate strength to prevent abrupt, violent failure (Vutukuri et al, 1974). In the last twenty years or so, however, the advent of servo-controls connected to the hydraulics of a frame actuator has enabled loading to occur according to chosen sensor analogue outputs. This, coupled with increasingly sophisticated computer control, has enabled investigators to study the post-failure of Class 2 rocks using a variety of independent variables for control signals such as lateral strain, inelastic strain and even acoustic emission rates.

In April of 1987, an MTS 880 Rock Mechanics Test System was made fully operational at the Canadian Mine Technology Laboratories (CMTL) in Ottawa. Major components of the system include: a 5200 kN stiff load frame, a high temperature/high pressure triaxial cell (accommodating samples up to 10 cm in diameter), a PDP11/73 computer and the associated hardware to control twin 5 gpm servo-valves. A detailed outline of the system is provided by Gorski (1987).

As part of an equipment familiarization exercise, post-failure testing was conducted on a sample suite obtained from borehole URL1 which is located in the Lac du Bonnet batholith near Pinawa, Manitoba. It is the purpose of this report to outline the procedure followed during testing, summarize the data and present some preliminary observations and conclusions based on both the sample results and machine capabilities.

IDENTIFICATION OF SPECIMENS

Eleven specimens were obtained from borehole URL1 around the 187 m and 286 m. horizons. The intersected formations can be classified as meduim to coarse grain granites. Massive and grey to greenish grey in colour, they have an average mineral composition of 29.4% quartz, 27.5% K-feldspar, 37.1% plagioclase, 3.5% biotite and 2.5% of all other accessory minerals such as muscovite, chlorite epidote, apatite, magnetite, sphene and sericite etc.

DESCRIPTION OF TEST MEASUREMENTS

Traditional uniaxial testing generally involves loading at some pre-determined stress (σ) or strain (ϵ) rate (ie. σ or $\epsilon = constant * time$). As mentioned earlier, if either of the control variables increases monotonically throughout the desired stress/strain range and the load frame is sufficiently stiff, then the test can be performed successfully as illustrated in Figure 1. Class 2 behaviour (idealized in Figure 2), however, would result in the control signal becoming unstable shortly after point A was reached, usually causing violent failure.

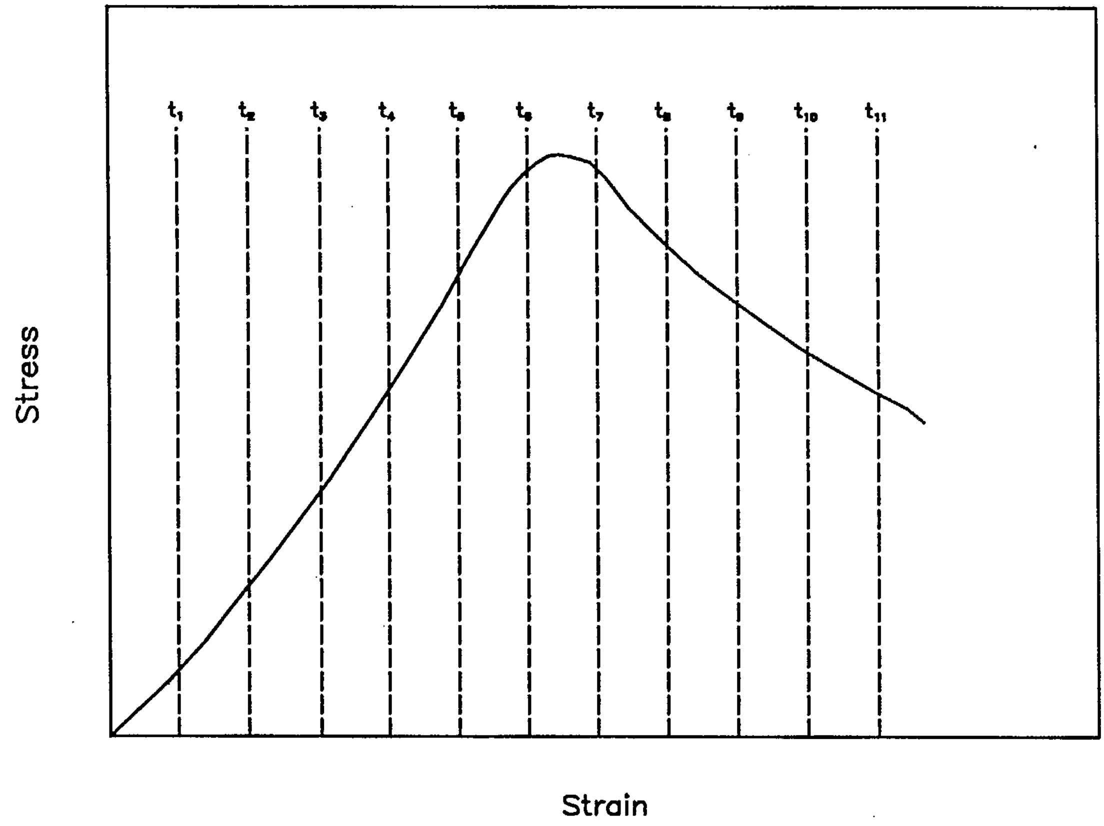

Fig. 1: Class 1 strain rate controlled uniaxial test

Okubo and Nishimatsu (1985) circumvented this problem by modifying the strain signal according to the equation;

$$\epsilon - \frac{\sigma}{E'} = constant * time \tag{1}$$

E' in equation 1 represents an arbitrary modulus value which lies somewhere between

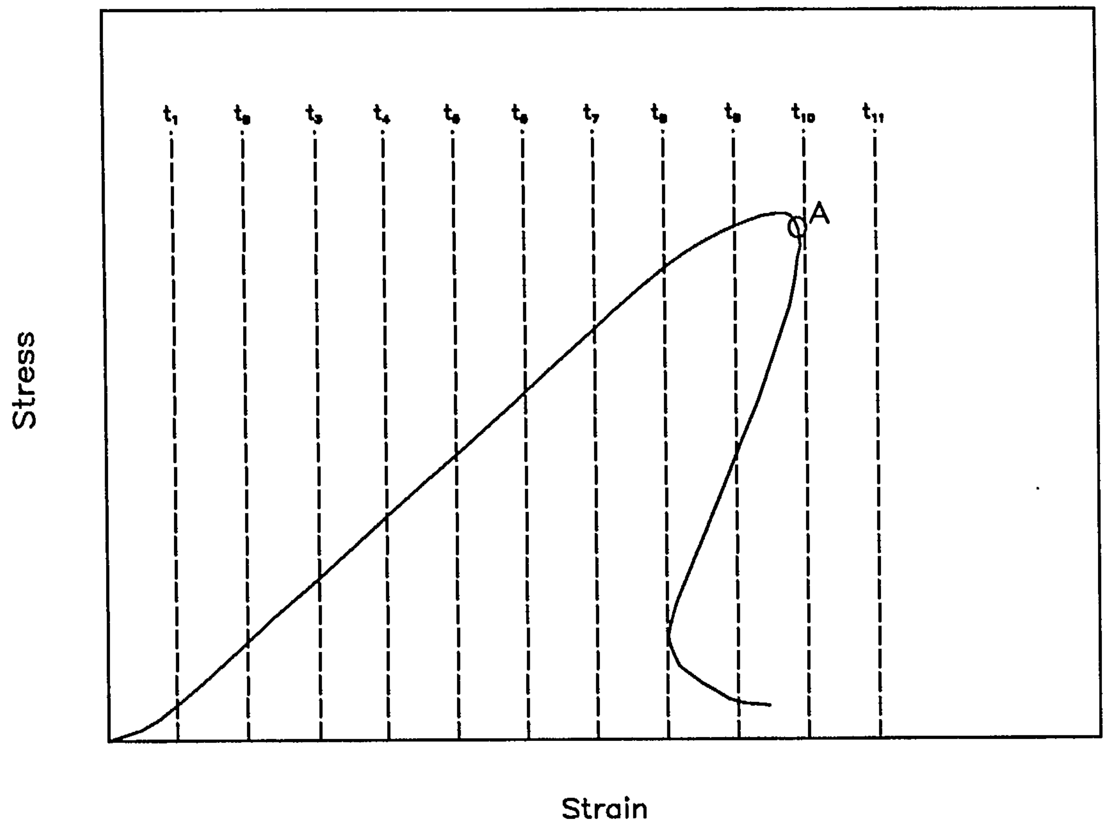

Fig. 2: Class 2 strain rate controlled uniaxial test

the expected pre- and post-failure moduli for the rock type in question. $\frac{1}{E'}$ or the 'gain' alters the signal in such a way as to allow control throughout the post-failure region even if the post-failure modulus is positive (Figure 3).

Platen to platen linear variable differential transducers (lvdt) were used to monitor specimen deformation as well as provide input for the control signal during testing. This necessitated using a 'system' modulus including upper platen, specimen and lower platen deformations when determining the control signal and, specifically, E'. Axial and circumferential strain gauges were also attached at mid-height of the sample and were recorded along with load and lvdt readings every three seconds throughout the test. The pre-failure axial strain readings were used in calculating the platen deformation correction to be applied to lvdt measurements made throughout the loading cycle.

The lvdt displacement versus load was also recorded for each specimen on a Hewlett Packard XYY recorder.

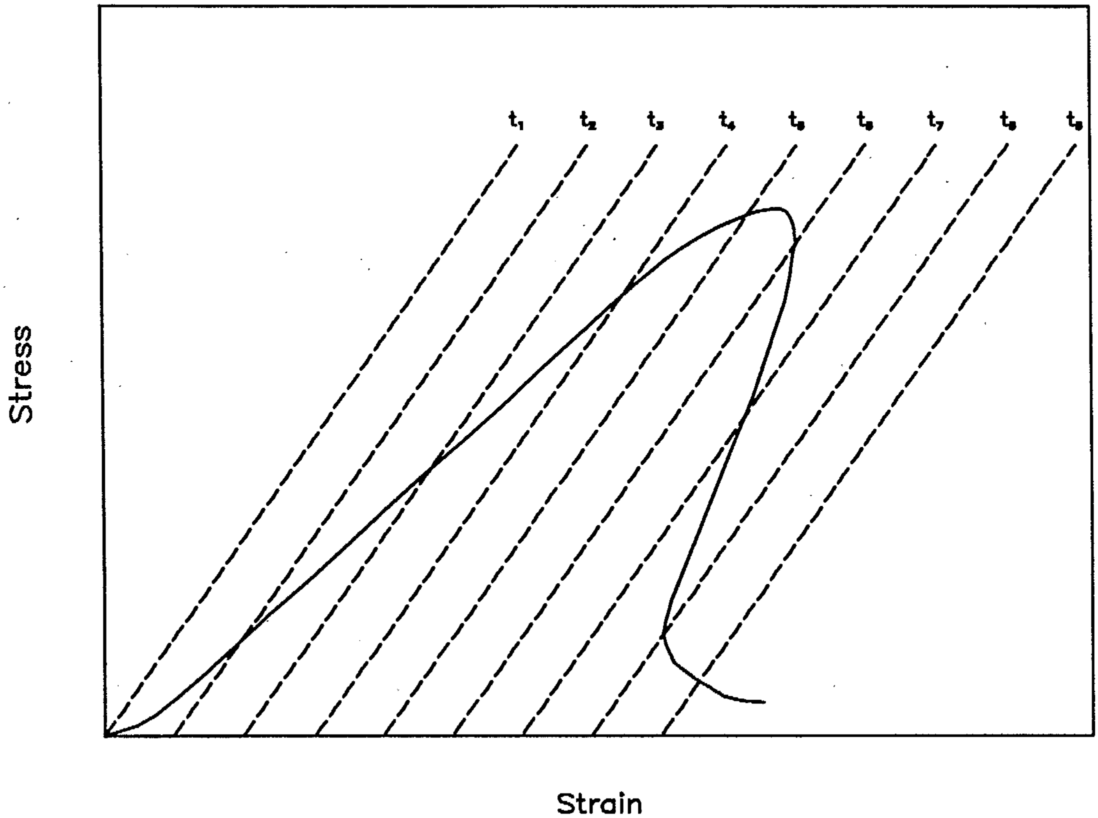

Fig. 3: Class 2 modified signal controlled uniaxial test

DATA TREATMENT AND SUMMARY

Data reduction was carried out in the same manner as outlined by Jackson and Boudreau (1984). Uniaxial compressive strength, secant and tangent moduli of elasticity at 50% of the failure load and Poisson's ratio were determined for each specimen and are summarized in Table 1 along with specimen dimensions. Figures 4 through 14 are corrected, computer generated plots of circumferential and axial strain versus stress for each sample.

Mean values of 153 MPa for uniaxial compressive strength, 65.48 GPa for tangent modulus of elasticity, 56.99 GPa for secant modulus of elasicity and 0.22 for Poisson's ratio were determined for the sample suite. The population also yielded standard deviations of 13 MPa, 4.58 GPa, 4.10 GPa and .03, respectively.

OBSERVATIONS AND CONCLUSIONS

The mean uniaxial compressive strength of 153 MPa ($\sigma^2 = 13$ MPa) is approximately

Table 1: Summary of Specimen Dimensions and Mechanical Properties

Specimen Identification	Length (mm)	Diameter (mm)	Weight (g)	Density (g/cc)	Uniaxial Compressive Strength (MPa)	Tangent Modulus of Elasticity (GPa)	Secant Modulus of Elasticity (GPa)	Poisson's Ratio
URL1-187.3	90.02	44.70	371.58	2.63	141	68.00	62.54	0.20
URL1-187.4	90.04	44.70	370.62	2.62	182	64.99	56.22	0.25
URL1-187.6	90.26	44.70	373.13	2.63	161	64.63	56.40	0.26
URL1-187.7	90.66	44.70	374.69	2.63	165	72.32	66.01	0.24
URL1-284.5	98.08	44.80	407.04	2.63	158	63.26	53.83	0.26
URL1-285.1	94.52	44.99	394.14	2.62	146	55.17	53.29	0.21
URL1-285.2	93.38	49.82	390.40	2.65	154	67.10	57.62	0.23
URL1-286.0	93.38	44.62	383.78	2.63	151	61.03	53.28	0.15
URL1-286.2	94.38	44.69	389.58	2.63	145	69.60	56.47	0.22
URL1-286.3	94.20	44.64	385.82	2.62	152	67.25	57.36	0.23
URL1-286.5	94.26	44.67	390.33	2.64	132	66.99	53.89	0.21

19% lower than the 188 MPa ($\sigma^2 = 34$ MPa) previously determined for Lac du Bonnet samples obtained from similar depth horizons (ie. 280.53 - 357.45 m.) (Jackson, 1984). Houpert (1970) noted that, in granites, a decrease in compressive strength was observed with decreasing loading rates. Uniaxial testing on Lac du Bonnet granites conducted prior to this program employed loading rates in the range of 0.8 to 1.0 MPa/sec. Rates of the order of 0.2 MPa/sec were normal for this program.

The slower rate of loading has also resulted in small localized failure occurring before ultimate strength is reached. As can be clearly seen from the lvdt readings for the stress/strain plots of samples URL1-284.5, 285.1, 286.0, 286.2, 286.3 and 286.5, samples were being compressed throughout the loading cycle even though some relaxation (unloading) was experienced in the region of the axial strain gauges. Hudson et. al. (1971) noted that in many cases, Class 2 behaviour was probably caused by non-uniform failure in the specimen; as one region of the specimen is loaded and fails, the rest of the specimen remains intact and is elastically loaded and unloaded. This type of behaviour was not observed during previous uniaxial testing programs where higher loading rates were employed.

Discussion of the dependence of strain and compressive strength on the rate of loading leads, inevitably, into the area of of viscoelastic theory or 'creep'. While creep in hard igneous rocks should not be signifigant at pressures less than 50% of their uniaxial compressive strength, Q_u, (Goodman, 1980), vaults located 1000 m below surface in the Canadian Shield can be subject to horizontal stresses up to 70 MPa (Herget, 1980). The introduction of an underground opening under these stress conditions could result in localized stresses exceeding 50% of Q_u causing creep to become a design factor. Also, the effect of temperature, while not well documented for granites, shows some evidence of accelerating creep as it increases (Rummel, 1969). The long term and elevated temperature nature of an underground nuclear waste repository, therefore, may make the study of creep potential of the URL formation advisable.

The mean tangent modulus of elasticity of 65.48 GPa agreed very well with previous results which exhibited a mean value of 64.7 GPa ($\sigma^2 = 8.9$ GPa). The Poisson's ratio of 0.22 also agreed well with the previously determined mean of 0.24 ($\sigma^2 = .03$).

In general, the new CMTL test system performed up to expectations. However, post-failure curves proved to be rougher than those obtained by Okubo and Nishimatsu. This can be attributed to the difference in the size of the actuators of the two systems. Some trade off in response time was necessary with the CMTL test system to achieve a 5200 kN maximum load capability. The lower capacity, faster acting ram of the Japanese system is better able to react to the control signal during post failure. CANMET is currently looking into the possibility of obtaining a smaller auxilliary frame which will be used with the existing system's hydraulics and computer control to enhance overall system capabilities.

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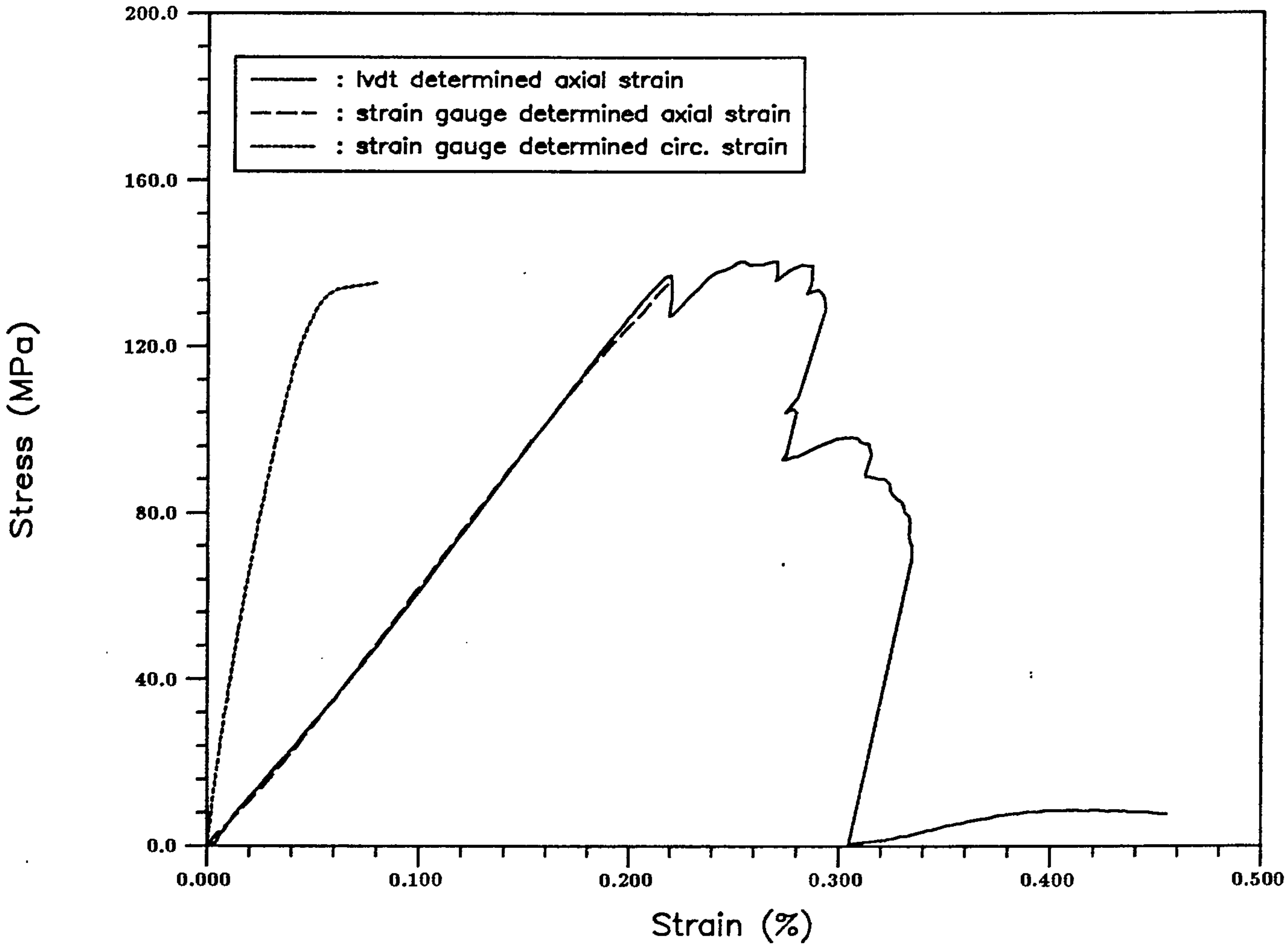

Fig. 4 : Stress/strain curves for Lac du Bonnet granitic specimen URL1–187.3

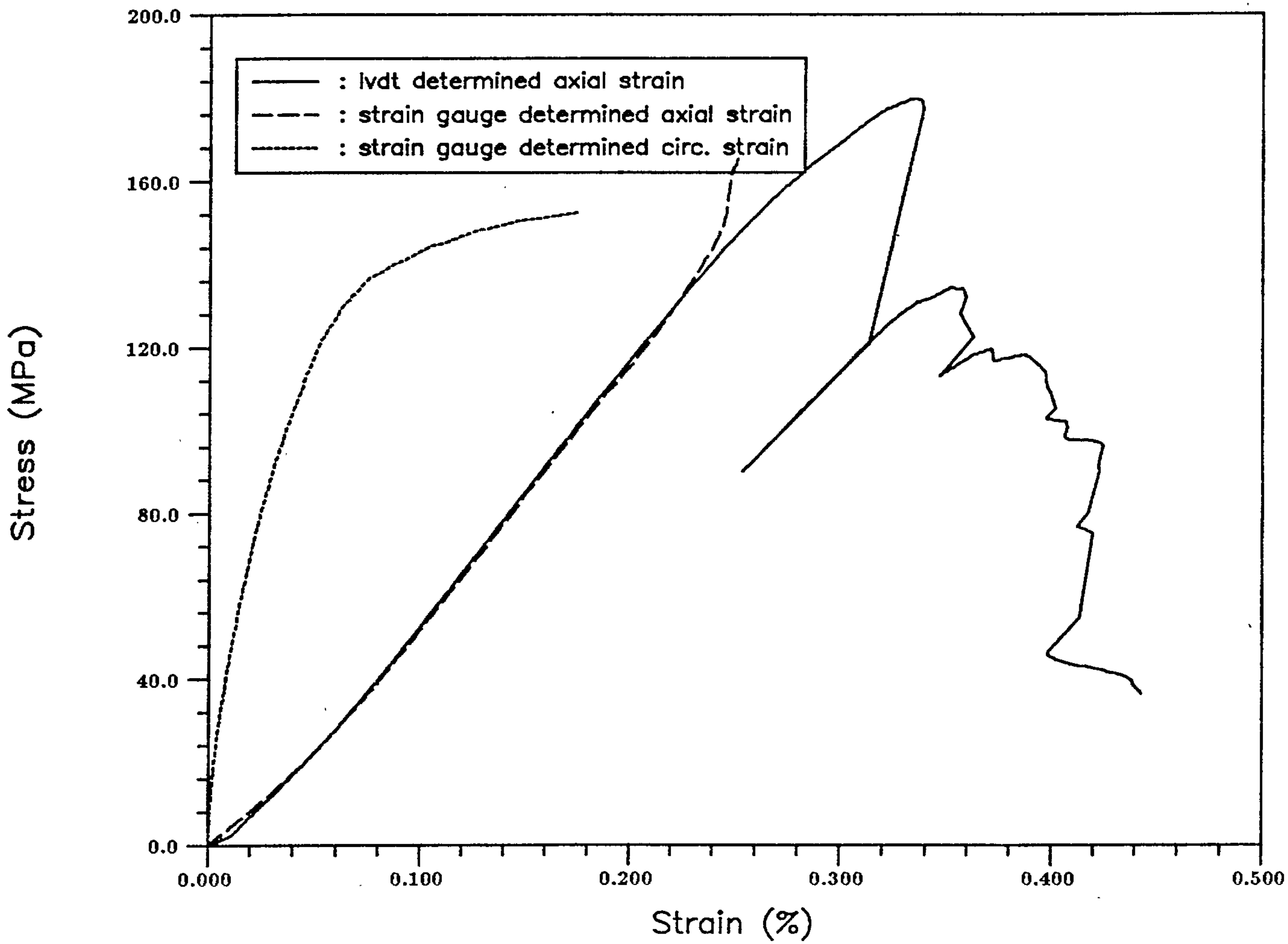

Fig. 5 : Stress/strain curves for Lac du Bonnet granitic specimen URL1–187.4

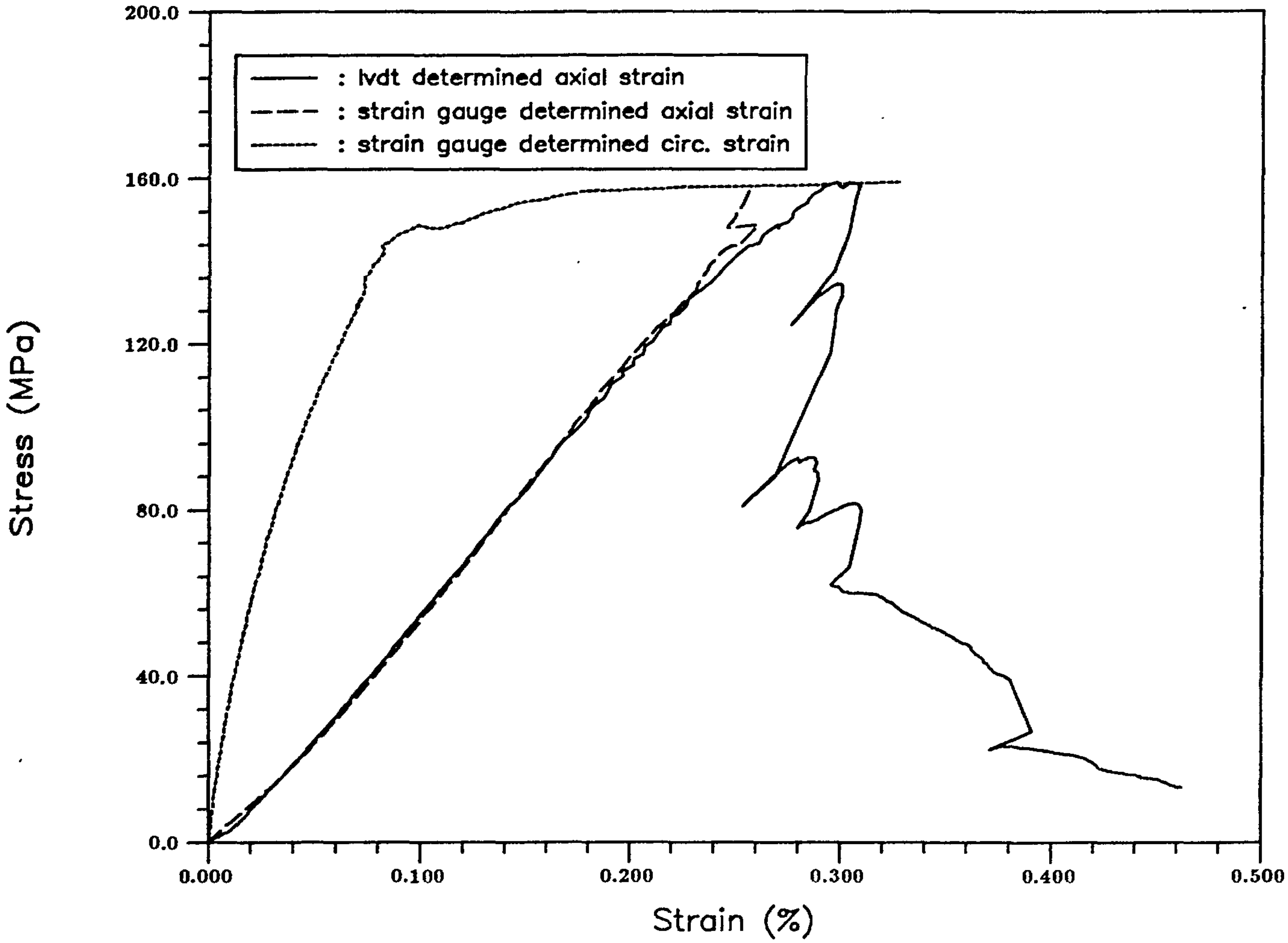

Fig. 6 : Stress/strain curves for Lac du Bonnet granitic specimen URL1–187.6

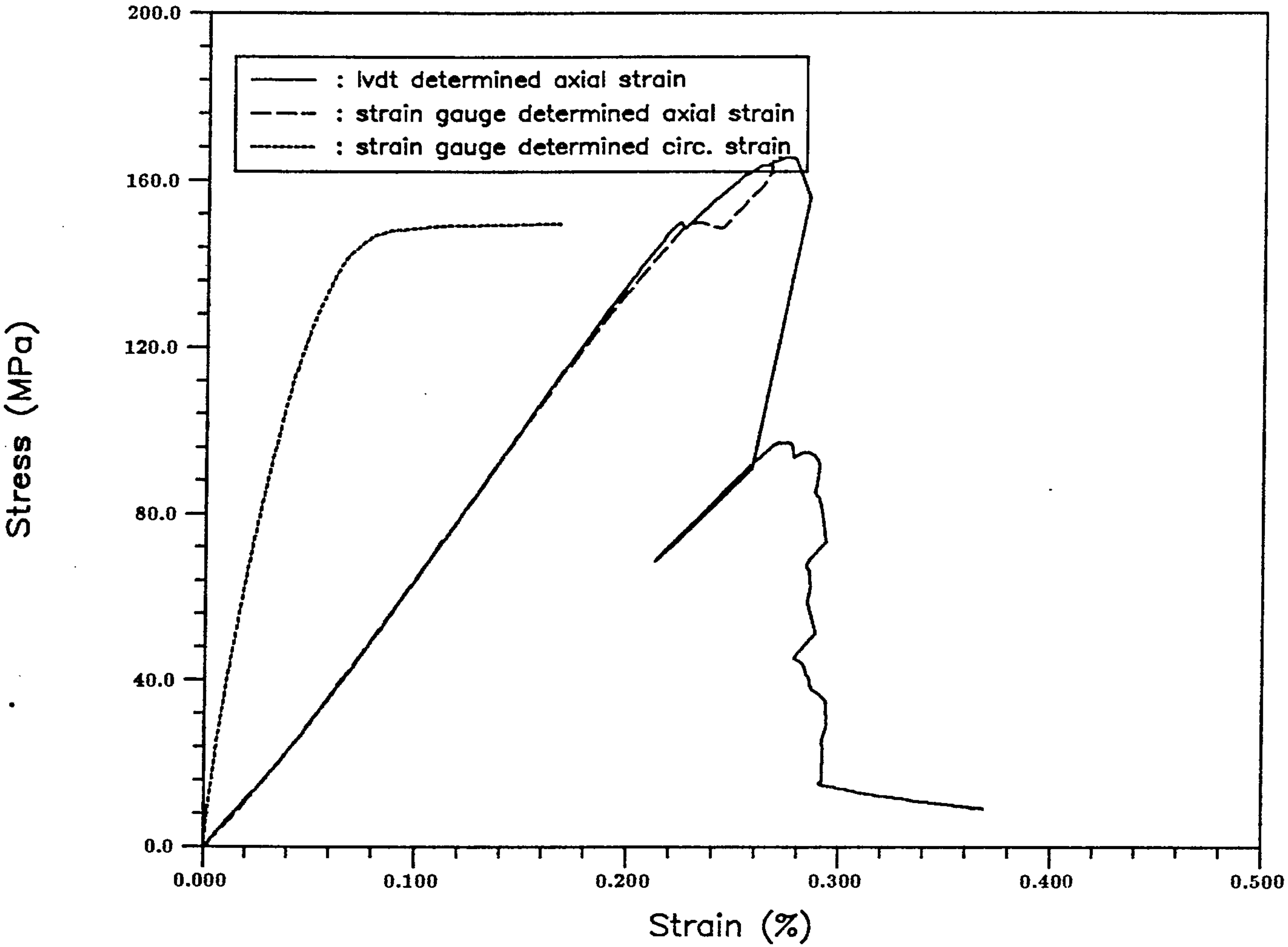

Fig. 7 : Stress/strain curves for Lac du Bonnet granitic specimen URL1−187.7

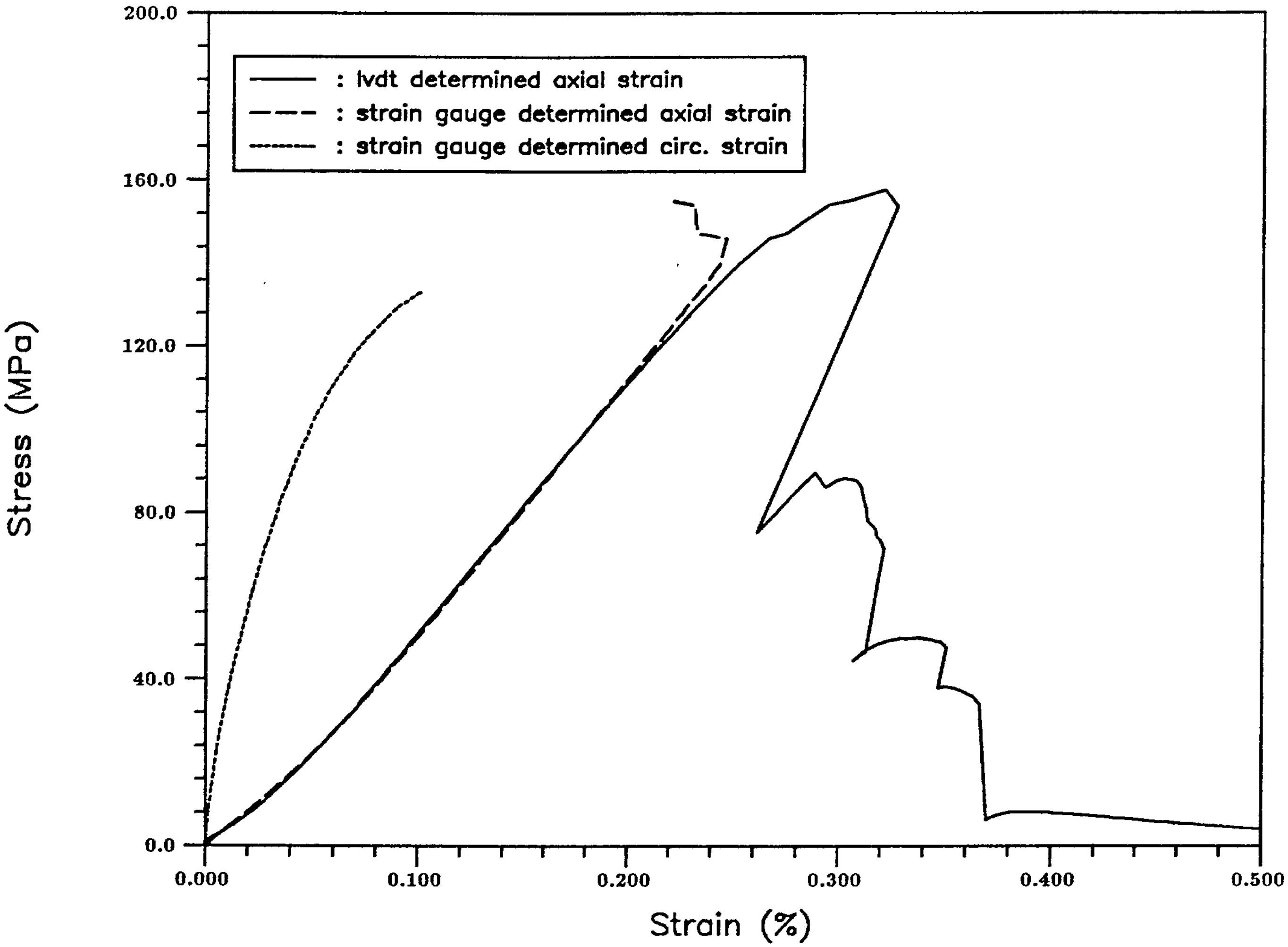

Fig. 8 : Stress/strain curves for Lac du Bonnet granitic specimen URL1−284.5

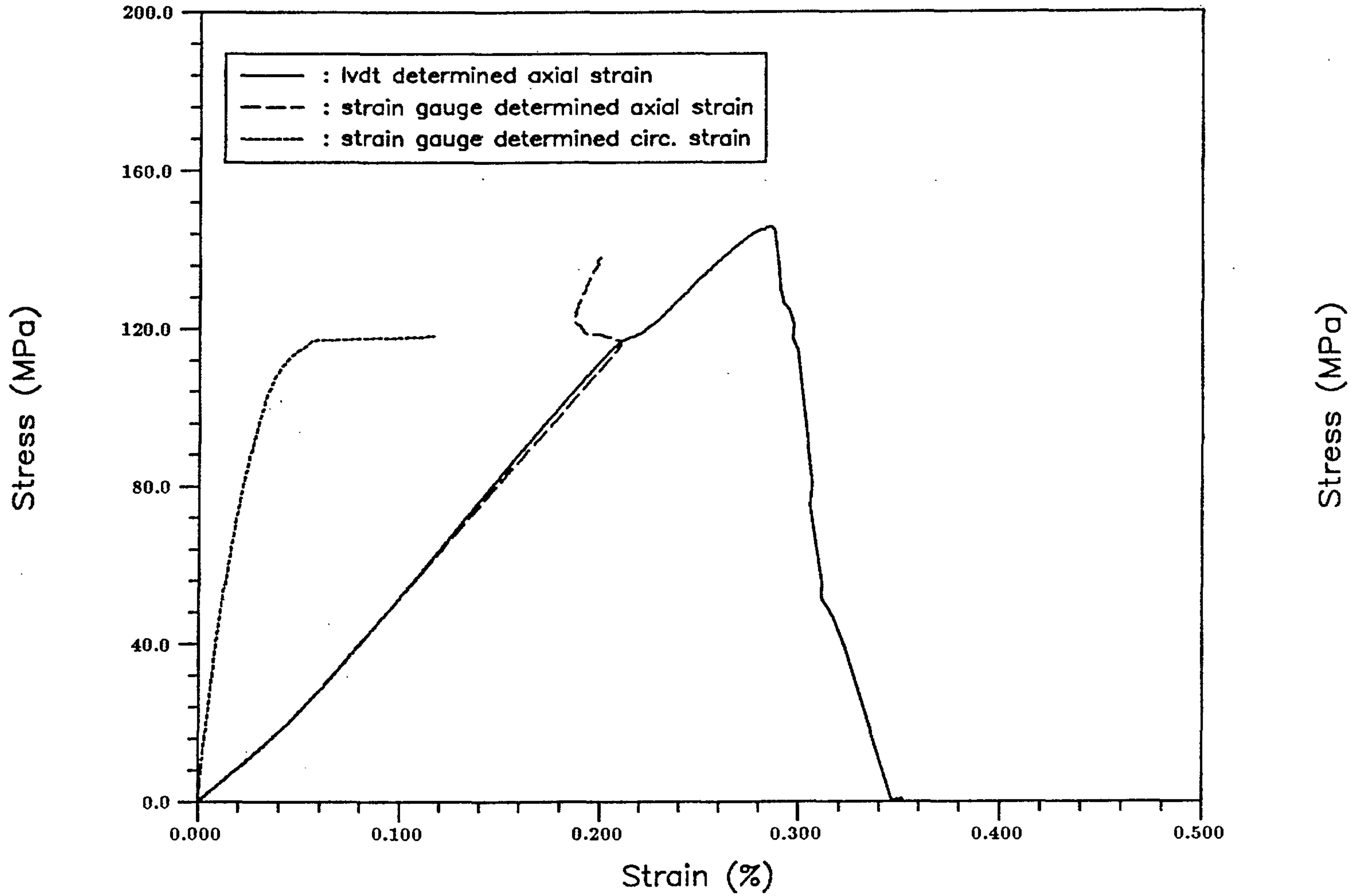

Fig. 9 : Stress/strain curves for Lac du Bonnet granitic specimen URL1−285.1

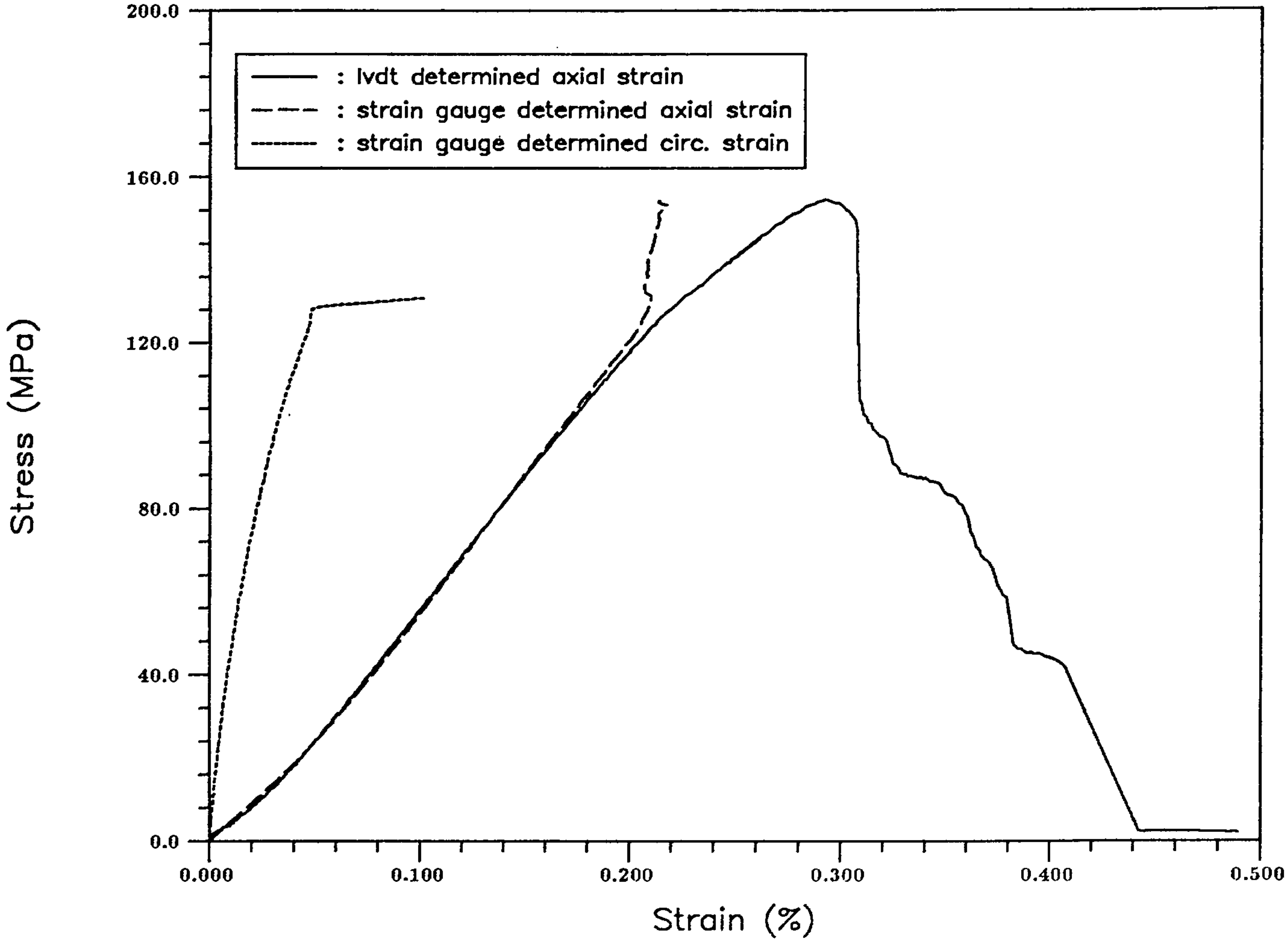

Fig. 10 : Stress/strain curves for Lac du Bonnet granitic specimen URL1 285.2

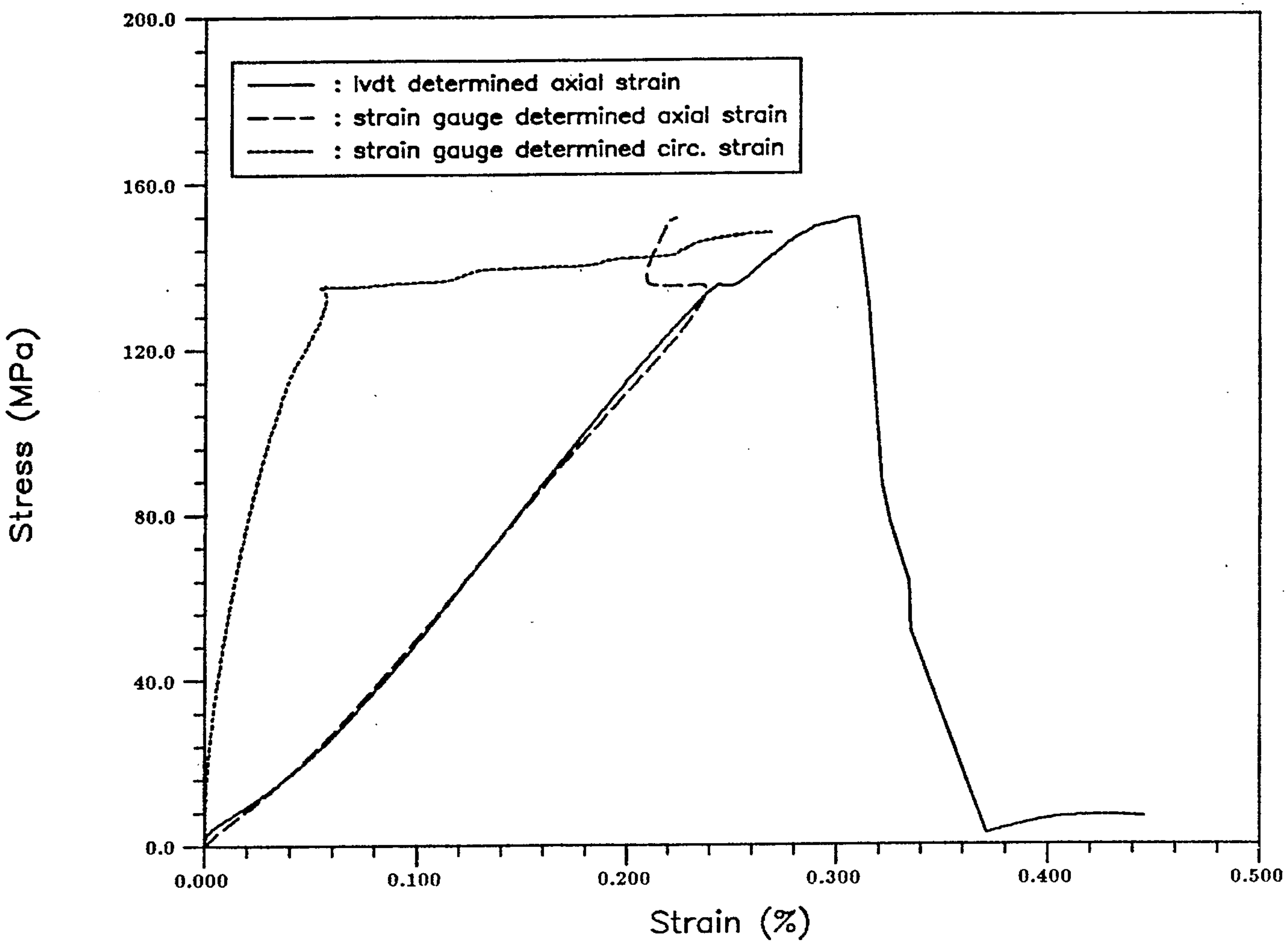

Fig. 11 : Stress/strain curves for Lac du Bonnet granitic specimen URL1 286.0

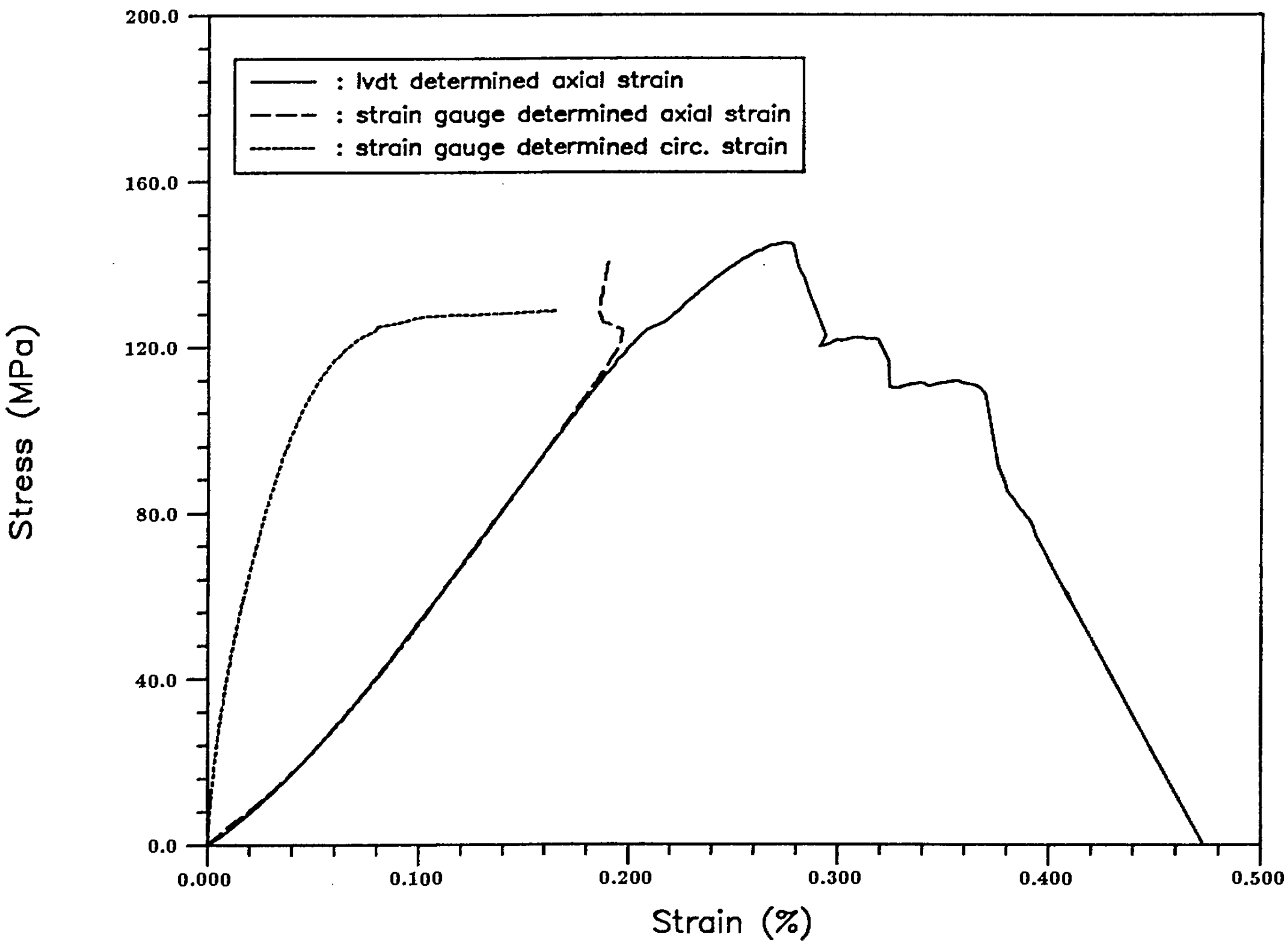

Fig. 12 : Stress/strain curves for Lac du Bonnet granitic specimen URL1—286.2

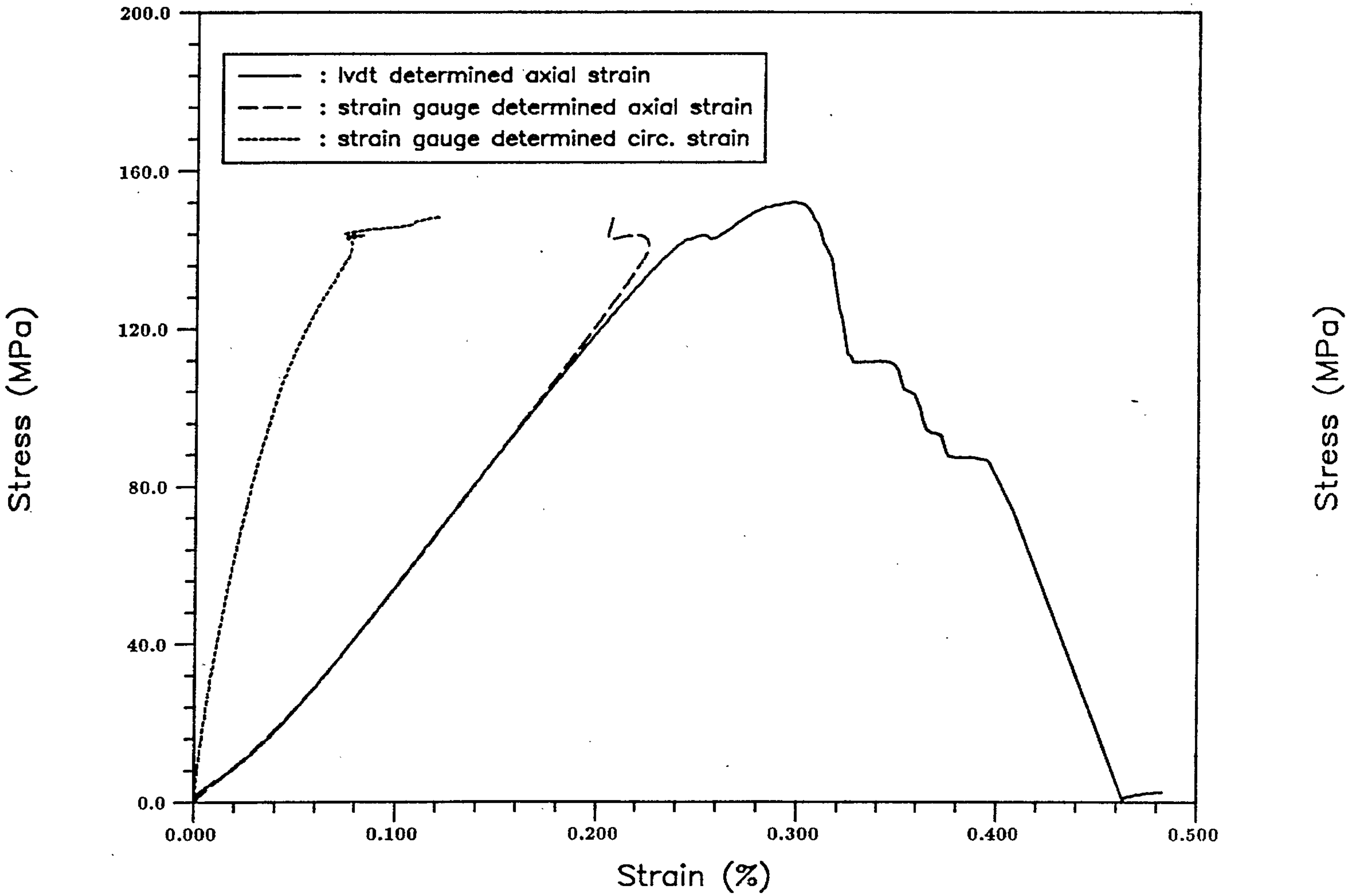

Fig. 13 : Stress/strain curves for Lac du Bonnet granitic specimen URL1–286.3

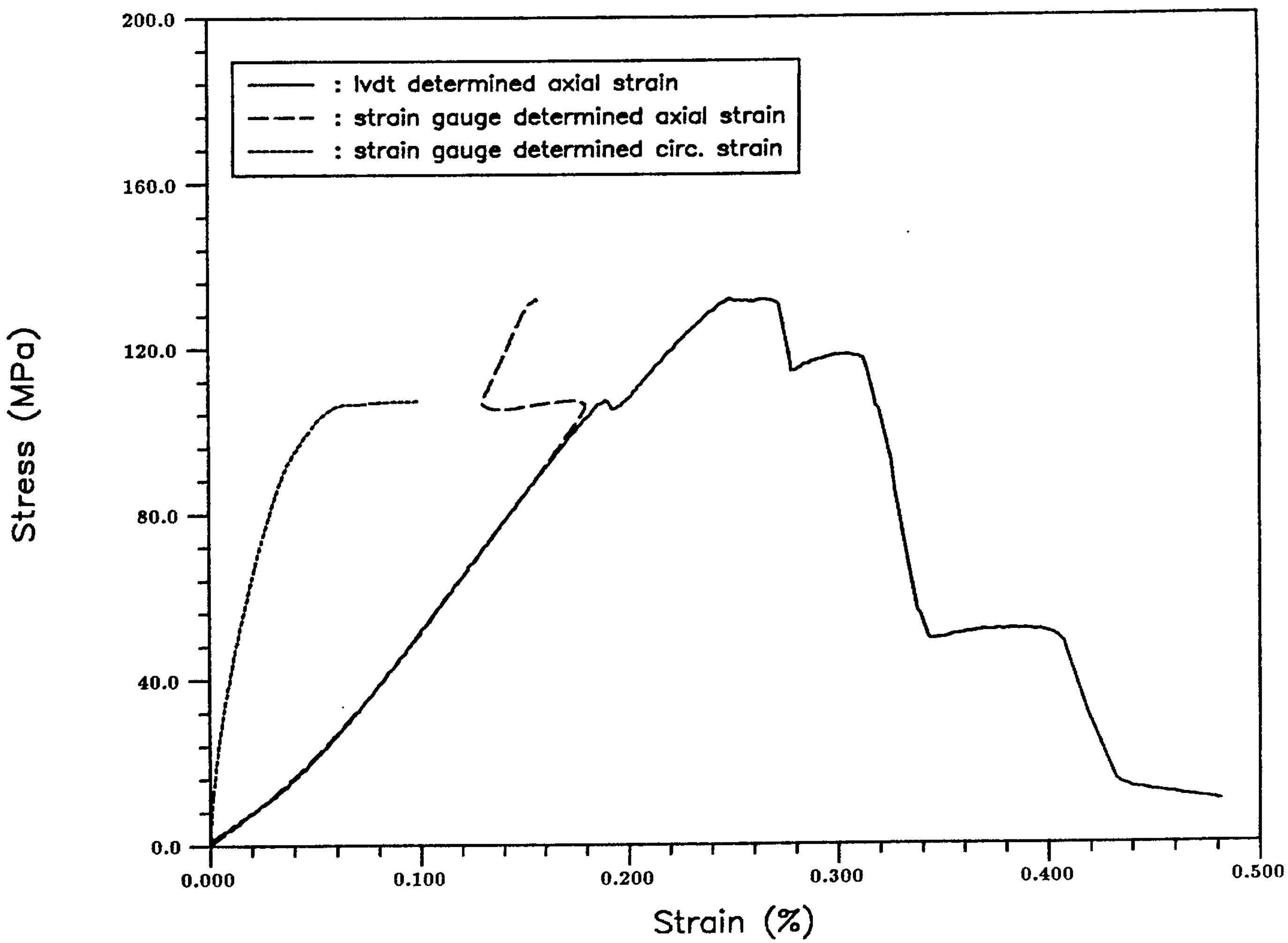

Fig. 14: Stress/strain curves for Lac du Bonnet granitic specimen URL1–286.5