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Effective stress testing of peat

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Introduction

- Laboratory methods used to determine the strength properties of peat are generally the same as for mineral soils, without special consideration given to the fibre content, high compressibility or relatively high permeability and gas content of fibrous peats (Farrell, 2012)

- Well documented that triaxial compression of fibrous peats produces very high effective angle of shearing resistance values in the range 40° to 60° (Landva & La Rochelle, 1983, Farrell & Hebib, 1998, Mesri & Ajlouni, 2007)

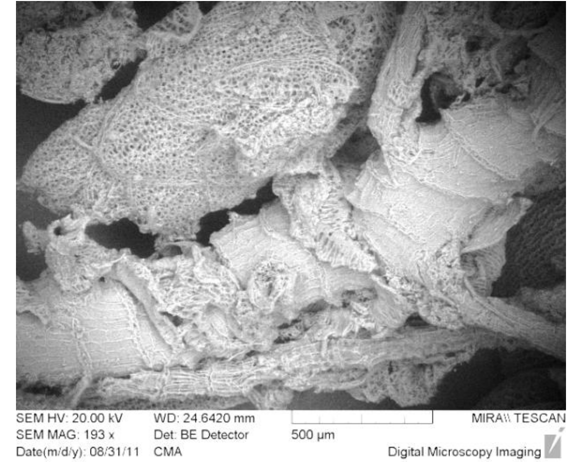
- An important effect of the presence of fibres in peat is the development under consolidated-undrained (CU) triaxial compression of high excess pore-water pressures, which can approximately equal the confining pressure (Yamaguchi et al., 1985, Farrell & Hebib, 1998, Boulanger et al., 1998) for axial strain beyond 5–10% in fibrous peat: makes any interpretation of phi' from CU triaxial compression testing difficult

- This research investigated the usefulness of isotropic consolidated drained (CID) triaxial compression testing applied to undisturbed, reconstituted and blended peats, and also the overall repeatability of the test method. The study presupposed that the effective-stress strength parameters are appropriate for peat and that these parameters can be obtained from CD triaxial compression tests

- This presentation summarises the findings of this research, full details of which have been published in O'Kelly, B.C., and Zhang, L., 2013. Consolidated-drained triaxial compression testing of peat. ASTM Geotechnical Testing Journal, 36(3): 310 −321. doi:10.1520/GTJ20120053

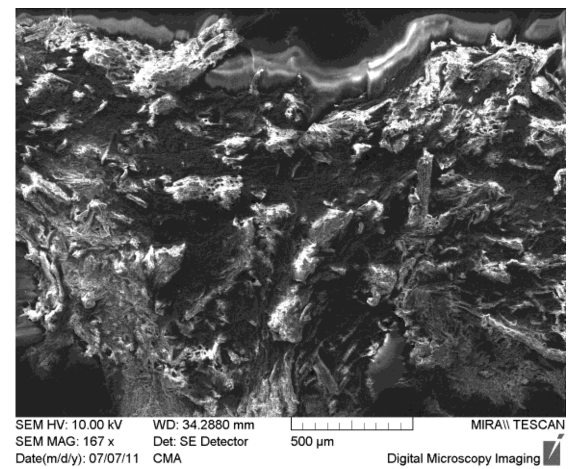
Test material

- Saturated peat blocks were obtained from 2.5 m below the ground surface at a recently-cut vertical face-bank at Clara bog, County Offaly, Ireland. The *in-situ* peat was heterogeneous, although with general cross-anisotropic 'mat' fabric



(a) Remoulded peat fibres

- Material consisted of *Sphagnum*, some *Sedge*, interspersed with plant and *Calluna* (shrub) remnants, along with a small portion of woody fibres provided by shrub rootlets. SCN–H_4 B_3 F_3(S) R_1(N) W_1(N) according to modified von Post peat classification system



(b) Blended material

Experimental Programme

- Undisturbed (U), reconstituted (R) and blended (B) test specimens, 38-mm dia. by 76-mm long, prepared for triaxial testing. Blended material prepared from remoulded peat using an electric handheld blender and passing the 425-μm sieve. Reconstituted and blended peat had fibre contents of 64% and 17% respectively

Specimen preparation:

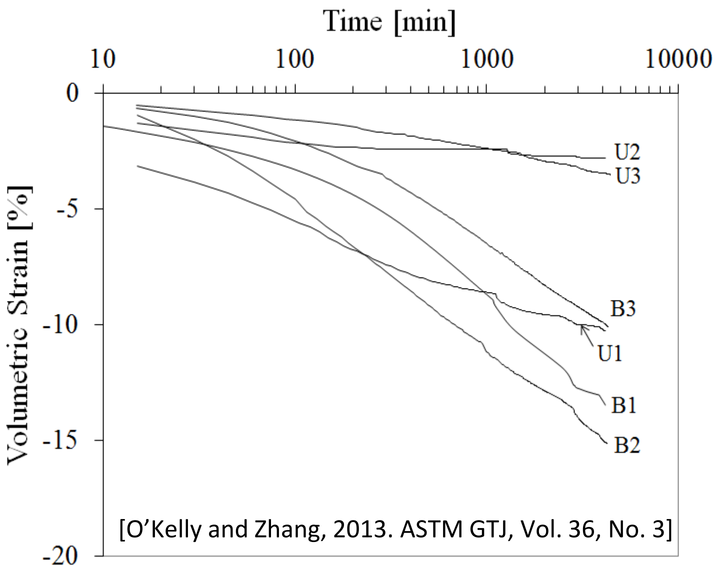
- Reconstituted and blended specimens prepared from peat cakes that had been 1D consolidated under two-way drainage to atmosphere and applied stresses of 6, 12 and 24 kPa maintained for periods of 15, 16 and 43 days, respectively

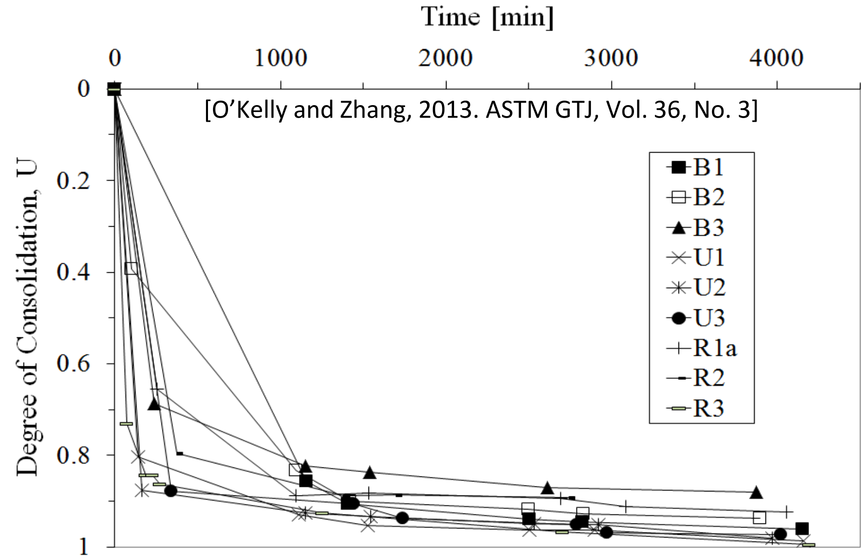
CID triaxial compression testing:

- All specimens were consolidated under the same effective confining pressure of 30 kPa (i.e. in normally-consolidated state), adopted considering the control accuracy (1 kPa) of the two pressure-volume controllers applying the cell- and back-pressures

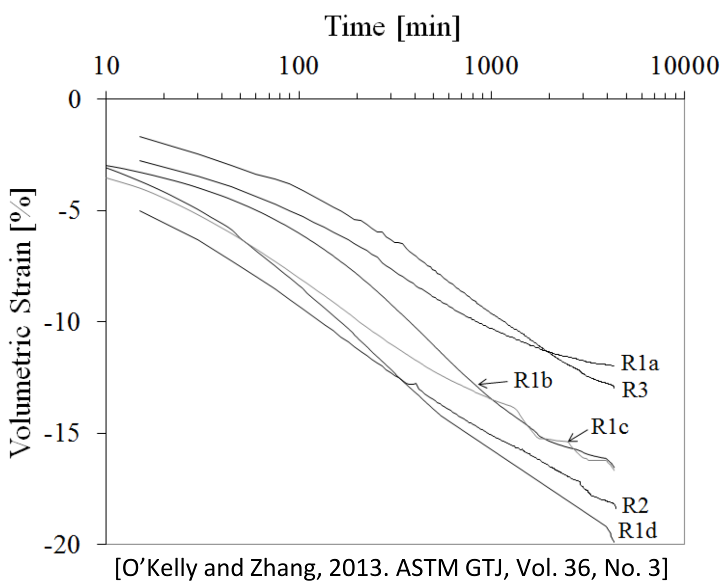
- Specimens consolidated under two-way vertical drainage (i.e. filter-paper side drains not fitted)
- Appropriate strain rate in triaxial compression determined by standard curve-fitting of measured volumetric strain–elapsed time response
- All triaxial tests, as well as the different stages of these tests, were of the same duration for consistency, apart from specimens R1b, R1c and R1d which were compressed at higher rates during the triaxial shearing stage to allow investigation of strain rate effects
- Strain rate during triaxial shearing stage adopted based on time period to achieve EOP for the test-material that consolidated slowest (i.e. blended peat): strain rate of typically 0.085%/h applied for all of the other specimens.

Triaxial consolidation stage:





Primary consolidation occurs relatively quickly, approx. 300–500 min required for substantive dissipation (*U* > 0.85–0.90) of excess pore-water pressures

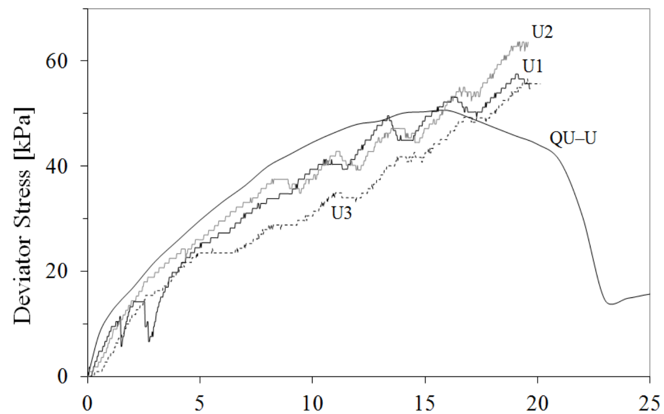


Volumetric strain response strongly related to the structure: Undisturbed >> reconstituted > blended material

Difference in volumetric strain response for a given material type unexpectedly large => natural variability of peat, but also suggests that <u>repeatability of triaxial consolidation tests on 38-mm dia. pseudo-fibrous and amorphous peat specimens may be generally poor</u> on account of the small size of the test specimen

Triaxial compression stage:

[O'Kelly and Zhang, 2013. ASTM GTJ, Vol. 36, No. 3]



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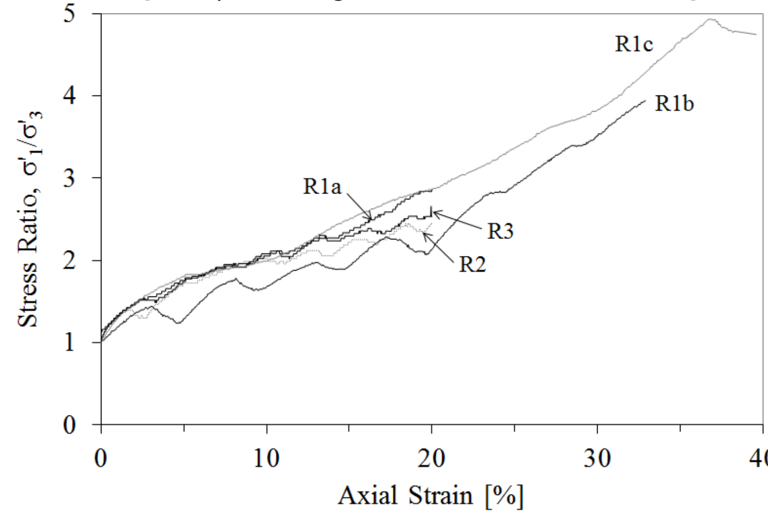
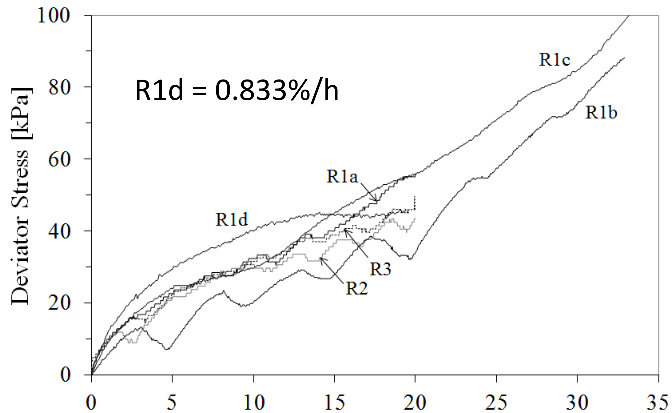
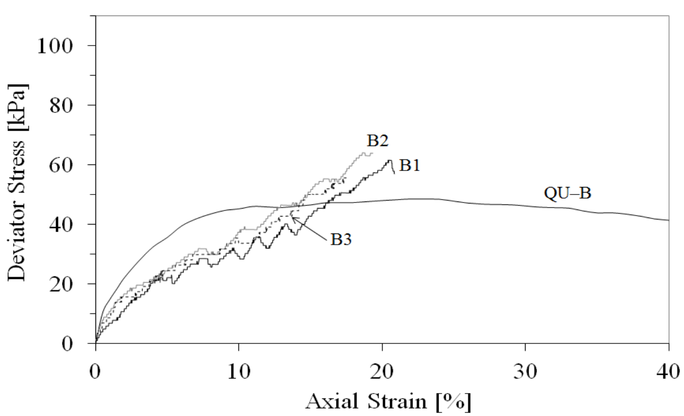






Conventional consensus is that, due to fibre effects, undisturbed and reconstituted specimens should mobilize higher shear resistance compared with blended peat in triaxial mode of shear

However, <u>for all three materials, values of deviatoic stress and stress ratio</u> mobilized for strain rates of 0.054–0.417 %/h <u>increased approximately linearly with increasing strain, without reaching a peak value, even for > 30% strain</u>

Hence none of the CID specimens could be taken to failure as defined by the Mohr-Coulomb criterion; hence most of the tests were terminated on reaching 20%

- For blended peat, the response was somewhat unexpected, structural and fibre affects would have been significantly less, but similar deviatoric stress – strain responses were measured for all three materials

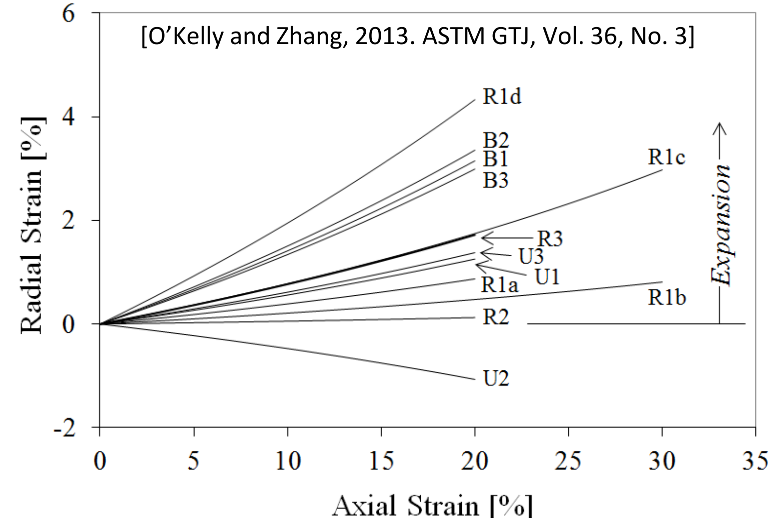
- Undisturbed specimen U1 and reconstituted peat specimen R2 did not appear to receive any significant strength enhancement from the *Calluna* remnants that were particularly noticeable during their preparation

- => Suggests mini-structure and fibre content do not have significant effects on resistance mobilized under drained triaxial compression of 38 mm diameter specimens. Similar findings reported for fibrous and amorphous peats by Edil and Wang (2000)

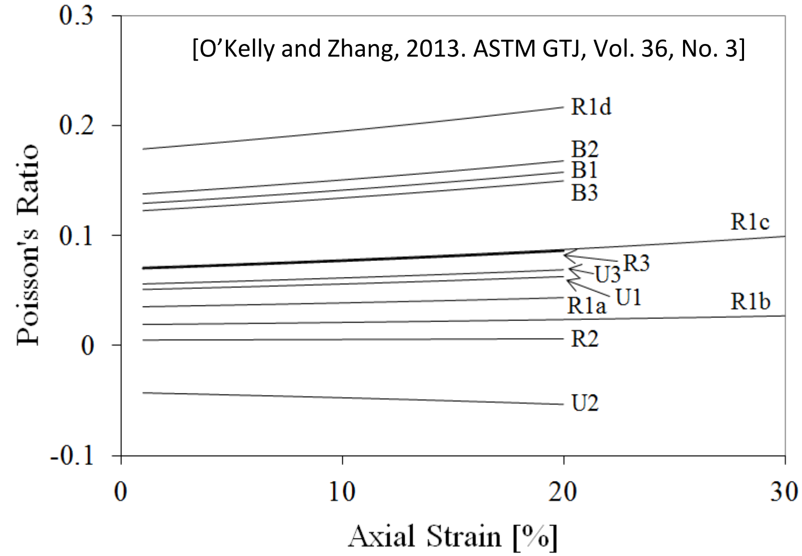
- Also consistent with research by Hanrahan and Walsh (1965) and Hanrahan et al. (1967) that qualitative behaviour of undisturbed and remoulded peat is similar and that pre-consolidation and anisotropic consolidation have little effect on the values of the strength parameters (Adams, 1965)

- Relatively large scatter in initial values of water content and void ratio measured between test-specimens of a given peat material did not appear to cause similar scatter in the deviatoric stress – strain responses. Agrees with Holubec and Langston (1972) from CD triaxial testing of fibrous peat and also with Adams (1965) and Hollingshead and Raymond (1972) from CU triaxial testing on Canadian muskegs

- Undisturbed and reconstituted peat specimens bulged only very slightly, essentially undergoing 1D compression, with deduced mean ν’ = 0.02–0.03 and 0.04–0.05, respectively, over the strain range 0–20%
  - For the fully-drained condition, full friction is mobilized between the fibres and also with the matrix material under the effective normal stress



- Uniformity of diametrical dimension over specimen height indicated that effects of specimen end-restraint due to platen friction were not significant



- Blended peat specimens deformed by bulging slightly, but without a shear plane developing, although significantly higher mean ν’ = 0.13–0.16 on account of the general isotropic structure and lower fibre content

Drained modulus of elasticity for the vertical direction determined from gradient of the deviatoric stress – axial strain plots, giving 110 –160 kN/m^2 under σ_3’ = 30 kPa

R1a R2 R3

- Considering responses of the 6 reconstituted peat specimens tested, apart from specimen R1d (0.833%/h), the other 5 specimens mobilized similar deviatoric stress and stress ratio values, increasing approx. linearly with increasing strain, even though they had been compressed at significantly different rates (0.077–0.417%/h)

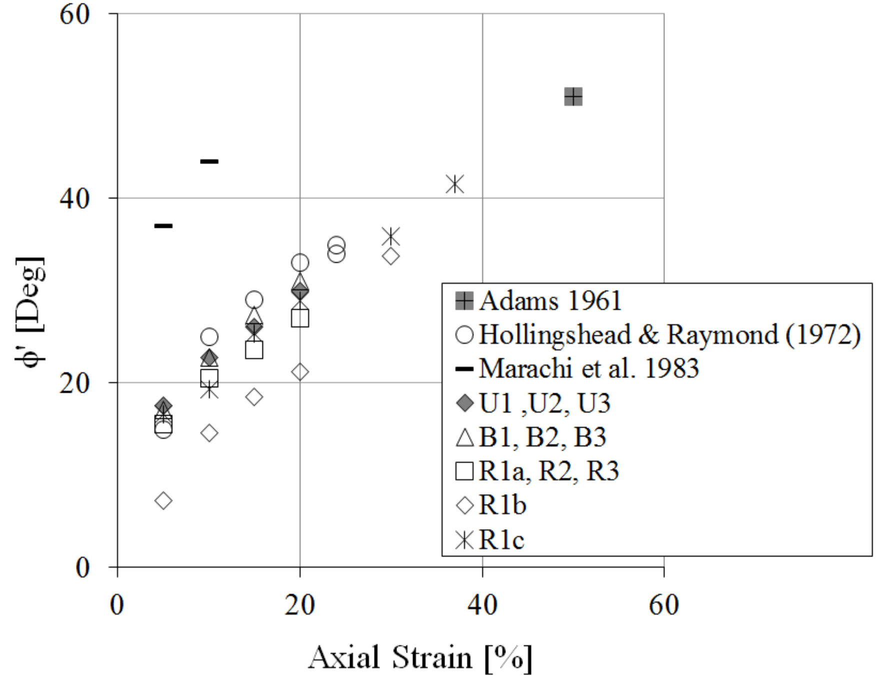
- Calculations based on the time periods of typically between 200 and 500 min required to achieve substantive dissipation of excess pore-water pressures ($U > 0.85$–0.90) during triaxial consolidation stage suggested strain rate of 0.28–0.47%/h would have been adequate for triaxial compression stage

$\Rightarrow$ drained triaxial compression stage could have been performed at about ten times quicker rate than that deduced from standard curve-fitting analysis of the experimental volumetric strain – elapsed time data to BS1377 (1990), without significant adverse effects on accuracy of deduced strength and stiffness properties

$\Rightarrow$ concurs with Edil & den Haan (1994) in that <u>strain rate in triaxial compression should be based on End of Primary estimations deduced from pore-water pressure measurements rather than measured volume change response</u>

- Value of phi' deduced from Mohr Circle of Stress analysis is strain-level dependent
- Assuming c' of zero and taking 20% axial strain as an arbitrary failure condition produced phi' values of 30.2±1.5°, 28.9±1.1° and 30.3±1.0° for undisturbed, reconstituted and blended peats respectively having *w* = 378–556%
- Extrapolation for the three peat materials indicated a range of phi' = 48–52^{o} for 50% strain: consistent with 51° reported by Adams (1961) for undisturbed fine-fibrous peat (*w* = 375–430%) specimens sheared over a three-month period, but under much higher σ_3' =138 kPa

[O'Kelly and Zhang, 2013. ASTM GTJ, Vol. 36, No. 3]



<u>Suggestion that for pseudo-fibrous and amorphous peats, phi' deduced from drained triaxial compression is unlikely to be an intrinsic property of the material, but rather is approximately proportional to strain level</u>, provided strain rate is sufficiently slow for substantial dissipation of excess pore-water pressures

<u>Given that c' value is established by projecting the Mohr-Coulomb envelope back to intersect the shear stress axis, c' deduced from drained triaxial compression is also unlikely to be an intrinsic material property since it is intimately dependent on the interpretation of phi'</u>

Conclusions regarding standard CIU triaxial testing of pseudo-fibrous *Sphagnum* peat

- Despite identical stress history and the same test conditions, significant differences arose in volumetric strain responses of 38mm diameter test-specimens for a given peat material
  => Natural variability of peat, even under controlled material preparation conditions
  => Generally poor repeatability of triaxial consolidation tests on peat specimens of small size

- Axial strain rate applied in triaxial compression tests should be based on End of Primary consolidation estimates deduced from measured pore-water pressure response

- Not possible to bring peat specimens to failure, with mobilized deviatoric stress and stress ratio values increasing approximately linearly with increasing strain, even for > 30%

- Significant differences in mini-structure and fibre content did not produce significant differences in shear resistance
  => deduced c’ and phi’ values are unlikely to be intrinsic material properties, but are largely a function of strain level, with higher phi’ values deduced for higher strain levels

- Fibre effects significant in limiting lateral expansion: undisturbed and reconstituted peats underwent 1D compression whereas blended peat deformed by bulging slightly. Significant lateral bulging of fibrous peat occurs in specimens compressed at too high a strain rate for sufficient dissipation of the excess pore-water pressures (similar to CU triaxial)

- From above observations, there are major difficulties with CD triaxial compression testing of peat and we agree with Landva et al. (1986), in that standard drained triaxial compression testing of peat is not particularly useful for determining its effective-stress strength properties

Acknowledgements

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Thank you