

Developing confidence in critical state soil mechanics

6. Drained txl compression of OCC *'consistency condition'*

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Key ideas (equations...)

- Yield surface: $F(\sigma, e, \zeta)$
 - If F < 0 then 'elastic'
 - If F=0 then 'plastic'
 - F>0 not admissible
- CONSISTENCY CONDITION
 - Must remain on the yield surface during yielding
 - mathematically: dF = 0

Rewrite OCC yield surface as:

$$F = 1 - \frac{\eta}{M} - \ln\left(\frac{p}{p_c}\right)$$

Consistency condition for OCC

For yield surface written as F=0, **consistency is dF=0**

$$\dot{\eta} = M\left(\frac{\dot{p}_c}{p_c} - \frac{\dot{p}}{p}\right)$$

Use with... $\eta_{j+1} = \eta_j + \dot{\eta}_j$

Consistency in drained triaxial



Euler method for OCC (forward difference)



Over to you

Either make copy of undrained worksheet or duplicate on same sheet

- Load path already defined on sheet (check dq/dp = 3)
- Add in column for...
 - Eta_dot (drained consistency condition)
- Modify
 - Step size
 - Calc of p_dot
 - Calc of eta.... $\eta_{j+1} = \eta_j + \dot{\eta}_j$
 - Increase number of steps to get 10% strain
- Graphs
 - Add volumetric strain plot & state plot
 - Add theoretical stress path to verify integration

	Drained OCC xls modifications																										
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Column Line Pie Bar Area Scatter Other Line Column Win/Loss Select Switch Plot										۲																	
1	A	B	; (2)		x = S9	F	G	Н			K	L	M	N	0	P	0	R	S	Т	U	v	w	X	Y -		
1	e calculatio	on				CONSTANTS	$5 \Delta \epsilon_q^p$	0.0002	lep size fo	or integration)															1		
2							MPa => kPa ratio K/G =	1.33	1																		
4						Dra	ained Dq/Dp = pacing Ratio =	3.00 2.72						-					•		1	V			-		
6	STEP	en1	FOR P	LOTTING	a		STEP 1:	Get soil state	e variables K	nc	Mi	STE	P 2: Apply Fle	denO n	denV n	STE	P 3: Use Harder dPc over Pc	ning Law Pr (UPDATED)	d eta	dn	P 4: Invoke Cor	nsistency condi	tion	STEP 5: d epV e	: Add in env		
8		(%)	(%)	(kPa)	(kPa)		-	(MPa)	(MPa)	(kPa)								(kPa)		(kPa)	(kPa)		(kPa)				
10	2	0.00	2.82%	200.00	5.35	0.731	0.020	2018	70	75.75	1.28	0.00	1.28	0.0002	0.0003	115.402	0.0295	75.75	0.03	1.8	201.77	0.027	10.66338	2.55E-05 2.51E-05	0.000		
11 12	3	0.06	5.57%	203.52 205.27	10.66	0.731	0.020	2035	70	77.94 80.15	1.28	0.05	1.23	0.0002	0.0002	115.370	0.0283	80.15 82.37	0.03	1.7	205.27 207.00	0.076	15.64981 20.80849	2.48E-05 2.44E-05	0.000		
13	5	0.12	10.93%	207.00	20.81	0.730	0.019	2070	72	82.37 84.61	1.28	0.10	1.18	0.0002	0.0002	115.307	0.0272	84.61 86.87	0.02	1.7	208.73	0.124	25.93554	2.41E-05 2.37E-05	0.001		
15	7	0.18	16.08%	210.44	31.03	0.729	0.019	2104	73	86.87	1.28	0.15	1.13	0.0002	0.0002	115.246	0.0261	89.14	0.02	1.7	212.14	0.170	36.09195	2.34E-05	0.001		
16	8	0.20	21.03%	212.14 213.83	41.12	0.728	0.018	2121 2138	74	91.42	1.28	0.17	1.11	0.0002	0.0002	115.217	0.0255	91.42	0.02	1.7	213.83	0.192	41.11999	2.3E-05 2.27E-05	0.002		
18 19	10	0.26	23.43%	215.51 217.18	46.11 51.07	0.727	0.018	2155	74	93.71 96.01	1.28	0.21	1.07	0.0002	0.0002	115.160	0.0246	96.01 98.32	0.02	1.7	217.18 218.83	0.235	51.07268 55.99619	2.24E-05 2.2E-05	0.002		
20	12	0.32	28.09%	218.83	56.00	0.727	0.017	2188	76	98.32	1.28	0.26	1.02	0.0002	0.0002	115.105	0.0236	100.64	0.02	1.6	220.47	0.276	60.88374	2.17E-05	0.003		
22	13	0.34	32.58%	222.10	65.73	0.726	0.017	2205	70	102.96	1.28	0.30	0.98	0.0002	0.0002	115.078	0.0231	102.96	0.02	1.6	223.72	0.296	70.54904	2.14E-05 2.11E-05	0.003		
23	15	0.40	34.76%	223.72	70.55	0.725	0.017	2237	77	105.29	1.28	0.32	0.96	0.0002	0.0002	115.026	0.0222	107.63	0.02	1.6	225.32	0.334	75.32586	2.08E-05 2.05E-05	E00.0		
25	17	0.45	38.99%	226.91	80.06	0.725	0.016	2269	78	109.97	1.28	0.35	0.93	0.0002	0.0002	114.976	0.0213	112.32	0.02	1.6	228.49	0.371	84.76574	2.01E-05	0.004		
27	19	0.51	43.07%	230.05	89.43	0.724	0.016	2300	79	114.66	1.28	0.39	0.89	0.0002	0.0002	114.932	0.0205	117.01	0.02	1.6	231.60	0.406	94.05141	1.95E-05	0.004		
28	20	0.53	45.04%	231.60 233.14	94.05 98.64	0.724	0.015	2316	80	117.01	1.28	0.41	0.87	0.0002	0.0002	114.905	0.0201	119.36	0.02	1.5	233.14 234.66	0.423	98.63557 103.1802	1.93E-05 1.9E-05	0.004		
30	22	0.59	48.89%	234.66	103.18	0.723	0.015	2347	81	121.71	1.28	0.44	0.84	0.0002	0.0002	114.860	0.0193	124.06	0.02	1.5	236.17	0.456	107.6851	1.87E-05	0.005		
32	23	0.61	52.59%	230.17	112.15	0.723	0.015	2302	82	124.06	1.28	0.45	0.82	0.0002	0.0002	114.838	0.0189	128.75	0.02	1.5	239.15	0.472	112.1499	1.84E-05	0.005		
33	25	0.67	54.38% 56.15%	239.15 240.62	116.57	0.722	0.014	2391 2406	82	128.75	1.28	0.49	0.79	0.0002	0.0002	114.795	0.0182	131.10	0.02	1.5	240.62	0.503	120.9585	1.78E-05 1.76E-05	0.005		
35	27	0.72	57.88%	242.07	125.30	0.721	0.014	2421	83	133.44	1.28	0.52	0.76	0.0002	0.0002	114.754	0.0175	135.77	0.01	1.4	243.51	0.532	129.6045	1.73E-05	0.006		
36	28	0.74	59.58% 61.24%	243.51 244.94	129.60	0.721	0.014	2435	84	135.77	1.28	0.53	0.75	0.0002	0.0001	114.734	0.0172	198.10	0.01	1.4	244.94 246.35	0.547	133.8661 138.0866	1.7E-05 1.68E-05	0.006		
38 39	30	0.80	62.88% 64.48%	246.35	138.09	0.720	0.014	2464	85	140.42	1.28	0.56	0.72	0.0002	0.0001	114.696	0.0165	142.74	0.01	1.4	247.75	0.574	142.2659	1.65E-05 1.63E-05	0.006		
40	32	0.85	66.05%	249.14	146.40	0.720	0.013	2491	86	145.05	1.28	0.59	0.69	0.0002	0.0001	114.658	0.0159	147.36	0.01	1.4	250.51	0.601	150.5007	1.6E-05	0.006		
41 42	33	0.87	67.60%	250.51 251.87	150.50	0.720	0.013	2505	86	147.36	1.28	0.60	0.68	0.0002	0.0001	114.640	0.0156	149.65	0.01	1.4	251.87 253.21	0.614	154.5561 158.57	1.58E-05 1.55E-05	0.006		
43	35	0.92	70.60%	253.21	158.57	0.719	0.013	2532	87	151.94	1.28	0.63	0.65	0.0002	0.0001	114.605	0.0150	154.21	0.01	1.3	254.54	0.639	162.5425	1.53E-05	0.007		
-		14 4 1	▶⊡ In	puts & Plot	s OCC	Calcs	OCC close	d form un	drained	+		0.04	0.04		0.0001		0.02-1	120.00			200.00	0.001	100.0000				
		Normal Vi	ew	Ready										S	im=0.027		•								1		





Let us program.... (validation then follows)



- Find <u>TXL Data.xls</u> in hand out
- Copy the sheet for test CID_682 to your OCC xls
- Plot ep1 vs q & epV vs ep1 on same plots as OCC
- $p_0 = 500 \text{ kPa}$; fix plot scales
- Adjust OCC properties to fit data





Time to stop cheating...

• For isotropic test and Cam Clay...

initial yield surface 'hardness' $p_c = p_0 / \text{SpacingRatio}$

Revert to void ratio form...

$$\ln(p_c) = \frac{\Gamma - e - \kappa \ln(p)}{\lambda - \kappa}$$



BREAK for TEA

What is wrong with Cam Clay...

- Back to <u>TXL Data.xls</u> in hand out
- Copy the sheet for test CID_667 to your OCC xls
- Switch data plot from test 682 to 667
- Set StepSize smaller.... 0.0001
- Set OCC properties...
 - P₀ = 130 kPa
 - *Г* = 0.82
 - $\bullet \ \lambda = 0.015$
 - *K* = 0.004
 - *M*=1.26

Worksheet plots CID_667 imported



	Drained OCC xls modifications																				
00												Carr	Clay_Cl	D_r1.xls	x						
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(Ins	ert Chart				Insert Sparklines			Data					Chart Qu	ick Layouts				
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1 e 2 3 4	A calculation	B	C	D	E	F CONSTANTS Dra	G Δε _q ^p MPa => kPa ratio K/G = ined Dq/Dp =	H 0.0002 1000 1.33 3.00	l (step size fo	J r integration)	K	L	M	N	0	P	Q	R	S	T	
5 6 7	STEP	ep1	FOR PL epV	OTTING	a	S;	sacing Ratio = STEP 1: G	2.72 Set soil state G	variables K		Mi	STEP	2: Apply Flo	wrule depQ_p	depV p	STE	P 3: Use Harden dPc over Pc	ing Law Pc (UPDATED)	d eta	dp	EP 4: Invo
8		(%)	(%)	(kPa)	(kPa)		-	(MPa)	(MPa)	(kPa)								(kPa)		(kPa)	(k)
9	1	0.00	0.00%	200.00	0.00	0.731	0.020	2018	69 70	73.58	1.28	0.00	1.28	0.0002	0.0003	115.402	0.0295	75.75	0.03	1.8	201
11	3	0.06	5.57%	203.52	10.66	0.731	0.020	2035	70	11.04	1.28	0.05	1.23	0.0002	0.0002	115.370	0.0283	80.15	0.03	1.7	205
12	4	0.09	8.28%	205.27	15.65	0.730	0.020	2053	71	80.15	1.28	0.08	1.20	0.0002	0.0002	115.338	0.0278	82.37	0.02	1.7	207
14	6	0.12	13.53%	208.73	25.94	0.729	0.019	2087	72	84.61	1.28	0.10	1.16	0.0002	0.0002	115.30/	0.0272	86.87	0.02	1.7	210
15	7	0.18	16.08%	210.44	31.03	0.729	0.019	2104	73	86.87	1.28	0.15	1.13	0.0002	0.0002	115.246	0.0261	89.14	0.02	1.7	212
16	8	0.20	18.58%	212.14	36.09	0.728	0.018	2121 2138	73	89.14 91.42	1.28	0.17	1.11	0.0002	0.0002	115.217	0.0256	91.42	0.02	1.7	213
18	10	0.26	23.43%	215.51	46.11	0.727	0.018	2155	74	93.71	1.28	0.21	1.07	0.0002	0.0002	115.160	0.0246	96.01	0.02	1.7	217
19	11	0.29	25.78%	217.18	51.07	0.727	0.018	2172	75	96.01	1.28	0.24	1.04	0.0002	0.0002	115.132	0.0241	98.32	0.02	1.7	218
20	12	0.32	28.09%	218.83	55.00	0.727	0.017	2188	76	98.32	1.28	0.26	1.02	0.0002	0.0002	115.105	0.0236	100.64	0.02	1.6	220
22	14	0.37	32.58%	222.10	65.73	0.726	0.017	2221	77	102.96	1.28	0.30	0.98	0.0002	0.0002	115.052	0.0226	105.29	0.02	1.6	223
23	15	0.40	34.76%	223.72	70.55	0.725	0.017	2237	77	105.29	1.28	0.32	0.96	0.0002	0.0002	115.026	0.0222	107.63	0.02	1.6	225
24	16	0.43	36.90%	225.32	75.33	0.725	0.016	2253	78	107.63	1.28	0.33	0.95	0.0002	0.0002	115.001	0.0218	109.97	0.02	1.6	226
26	18	0.43	41.05%	228.49	84.77	0.724	0.016	2285	79	112.32	1.28	0.33	0.91	0.0002	0.0002	114.970	0.0209	114.66	0.02	1.6	230
27	19	0.51	43.07%	230.05	89.43	0.724	0.016	2300	79	114.66	1.28	0.39	0.89	0.0002	0.0002	114.929	0.0205	117.01	0.02	1.6	231
28	20	0.53	45.04%	231.60	94.05	0.724	0.015	2316	80	117.01	1.28	0.41	0.87	0.0002	0.0002	114.905	0.0201	119.36	0.02	1.5	233
29	21	0.56	46.98%	233.14	98.64	0.723	0.015	2331	80	119.36	1.28	0.42	0.86	0.0002	0.0002	114.882	0.0197	121.71	0.02	1.5	234
31	23	0.61	50.75%	236.17	107.69	0.723	0.015	2362	81	124.06	1.28	0.46	0.82	0.0002	0.0002	114.838	0.0189	126.41	0.02	1.5	237
32	24	0.64	52.59%	237.67	112.15	0.722	0.015	2377	82	126.41	1.28	0.47	0.81	0.0002	0.0002	114.817	0.0186	128.75	0.02	1.5	239
33	25	0.67	54.38%	239.15	116.57	0.722	0.014	2391	82	128.75	1.28	0.49	0.79	0.0002	0.0002	114.795	0.0182	131.10	0.02	1.5	240
34	26	0.69	56.15%	240.62	120.96	0.722	0.014	2406	83	131.10	1.28	0.50	0.78	0.0002	0.0002	114.775	0.0178	133.44	0.02	1.5	242
36	28	0.72	59.58%	242.07	129.60	0.721	0.014	2421	84	135.77	1.28	0.52	0.75	0.0002	0.0001	114.734	0.0175	138.10	0.01	1.4	243
37	29	0.77	61.24%	244.94	133.87	0.721	0.014	2449	84	138.10	1.28	0.55	0.73	0.0002	0.0001	114.715	0.0168	140.42	0.01	1.4	246
38	30	0.80	62.88%	246.35	138.09	0.720	0.014	2464	85	140.42	1.28	0.56	0.72	0.0002	0.0001	114.696	0.0165	142.74	0.01	1.4	247
39	31	0.82	64.48%	247.75	142.27	0.720	0.013	2478	85	142.74	1.28	0.57	0.71	0.0002	0.0001	114.677	0.0162	145.05	0.01	1.4	249
40	33	0.85	67.60%	249.14	146.40	0.720	0.013	2491	86	145.05	1.28	0.59	0.69	0.0002	0.0001	114.658	0.0159	147.35	0.01	1.4	250
42	34	0.90	69.11%	251.87	154.56	0.719	0.013	2519	87	149.65	1.28	0.61	0.67	0.0002	0.0001	114.622	0.0153	151.94	0.01	1.3	253
43	35	0.92	70.60%	253.21	158.57	0.719	0.013	2532	87	151.94	1.28	0.63	0.65	0.0002	0.0001	114.605	0.0150	154.21	0.01	1.3	254
44	36	0.95	72.06%	254.54 auts & Plo	162.54	0.719	0.013	2545 form up	88 drained	+	1.28	0.64	0.64	0.0002	0.0001	114.587	0.0147	156.48	0.01	1.3	255









- OCC is beautiful mathematical construct
- Validates to real soil under very limited range of conditions
- OCC cannot deal with nearly everything encountered in practice
- Situation ~ 1975: " *Interesting, but CSSM a dead end* "

GAME CHANGER....

1985: State Parameter (Parry, 1958)

