QE
75
.U58d
79-1687
1979

C.1

BUREAU OF RECLAMATION DENVER LIBRARY
92071923

UNITED STATES DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

Texas Instruments Model 59 Hand-Calculator Program to Calculate Gravity Anomaly over 2-D Prisms of as Many as 18 Vertices

by

Donald N. Haines and David L. Campbell

U.S. Geological Survey, Denver, Colorado 80225

Open-File Report 79-1687

1979

Citation of particular manufacturers and model numbers does not constitute endorsement by the U.S. Geological Survey.

Although this program has been extensively tested, the U.S. Geological Survey cannot guarantee that it will give correct results in any or all particular applications.

TITLE GRAVITY : 2-D ANOMALY PAGE 1 OF 9

PROGRAMMER DONALD N. HAINES AND DAVID L. CAMPBELL DATE 6/27/78

TI Programmable Program Record

Partitioning (Op 17) 5.5.9.4.9 Library Module NONE USED Printer Optional Cards 2

(5 2nd Op 17)

PROGRAM DESCRIPTION

Program Description, Equations, Variables, etc. A Talwani-type program to calculate gravity anomaly due to a 2-dimensional prism with ≤ 18 vertices.

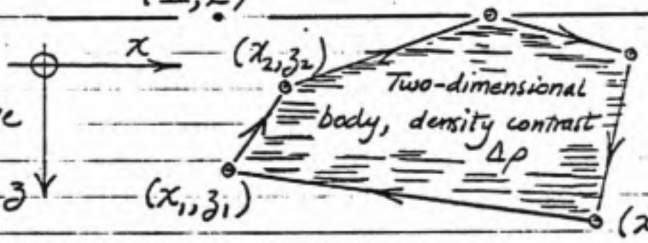
Eqn: $$\Delta g = 2G\Delta\rho \sum_{i=1}^{n} \frac{b_i}{d_i}\left\{a_i(z)\left[\ln R_{i+1} - \ln R_i\right] + a_i(x)\left[\theta_{i+1} - \theta_i\right]\right\}$$

where

$R_i^2 = x_i^2 + z_i^2$ $\quad a_i(x) = x_{i+1} - x_i$ $\quad b_i = x_i z_{i+1} - x_{i+1} z_i$

$\theta_i = \tan^{-1} x_i / z_i$ $\quad a_i(z) = z_{i+1} - z_i$ $\quad d_i = (a_i(x))^2 + (a_i(z))^2$

Geometry:



All coordinates w.r.t. arbitrary origin. (z positive downward.)

Body vertices $(x_i, z_i;\ i = 1, n)$ numbered clockwise around body. $n \le 18$

Units: Δg in milligals

x, z, X, Z in Km (default) or Kft (flag 0 set).

Δρ in g/cm³.

Reference: Grant, F.S., and West, G.F., 1965, Interpretation Theory in Applied Geophysics: New York, M^cGraw-Hill, p. 289, eqn. 10-7.

USER DEFINED KEYS	DATA REGISTERS (INV Ind)		LABELS (Op 08)
A Δρ	0 # Bodpts, n	40 ΔX	
B —	1 Loop index, i	41 Old θi	
C —	2 Δρ	42 ΣΔgi	
D Body point	3 2GΔρ	43 Ri+1/Ri	
E Field point	4-39 ↑ Body vertex coordinates ↓	44 Δθi	
A' —		45 bi	
B' —		46 ai(z)	
C' —		47 ai(x)	
D' Body index		48 X	
E' ΔX		49 Z	

FLAGS Kft 0 — 1 — 2 — 3 — 4 — 5 — 6 — 7 — 8 — 9

1014968-1

TITLE GRAVITY: 2-D ANOMALY PAGE 2 OF 9 TI Programmable Program Record

PROGRAMMER _____ DATE _____

Partitioning (Op 17) [5,5,9,4,9] Library Module None Printer Optional Cards 2

(5 2nd Op 17)

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Read in banks 1,2,3					
	Note: If you're new to TI calculators, the exact procedure is:					
	(a) Turn calculator on. If it is already on, turn it off and then back on to clear possibly troublesome display formats.					
	(b) Set partitioning, like this:	5	2nd	Op	17	559.49
	(c) Enter "0." and feed side 1 of card 1 into slot.		Display shows			1.
	(d) Enter "0." and feed side 2 of card 1 into slot.		Display shows			2.
	(e) Enter "0." and feed side 1 of card 2 into slot.		Display shows			3.
	If display blinks, something failed, so repeat the step.					
2	If input distances (x,z,X,Z) are to be in km, skip this step. If in kft, press		2nd	St flg	0	
3	Enter density difference	$\Delta\rho$ gm/cm^3			A	$\Delta\rho$
4	Input body vertices					
	(a) Initialize	(k=) 1		2nd	D	0
	(b) Enter successive body vertices working clockwise around body.					
		x_i			x$\pm$t	
		z_i			D	i
	● Up to 18 vertices may be entered.	Flashing "18." in display after this step means you tried to enter too many. Note vertex #1 is not repeated to close the body, as in some programs.				
5	(Optional) To calculate points on a profile (Z constant)	ΔX		2nd	E	ΔX
6	Enter field points	X			x$\pm$t	
		Z			E	Δg mgals
	● Repeat step for other field points, as desired, or press R/S for next incremented X.					
	● If the field point happens to coincide with the first or last body vertex (although not any other body vertices), the program will query the result it returns (display will flash and "?" is appended to printer output). Such results should be checked; for example, by recalculating Δg at a nearby field point which is not at an objectionable location, or by reordering body vertices so that the field point of interest does not lie on the first or last vertex. (See example, p. 9.)					

TI Programmable **Program Record**

PROGRAMMER _____ DATE _____

Partitioning (Op 17) [, , , ,] Library Module _____ Printer _____ Cards _____

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS		DISPLAY
7	To change body point k	k	2nd	D	n-1
		x_k		x⇄t	
		z_k		D	n=total # body pts.
	● Body point k (only) is changed via step 6. However, body point #1 may not be changed this way, for program then thinks it's at step 4a, and all body points must be re-entered.				
	● Body may be extended at any time via step 4b. This adds new body points, starting from previous nth body point.				
	● Steps 2,3,4,6, and 7 may be performed in various sequences, including between field calculations, to see the effect of changing one such parameter.				
8	To start a new body, clear		2nd	CMS	and go to step 2.

CARD LAYOUT

1 ◁ ▷ 2

GRAVITY: 2D Anomaly – Card 1 – 5OD17				
			Bod. index	ΔX
Δρ			X, Z	X, Z

3 ◁ ▷

GRAVITY: 2D Anomaly – Card 2 – 5OD17				

Comments

1. This program calculates gravity field due to only one body at a time. Still, multi-body models may be treated by using the program to calculate gravity anomaly for each body separately, and then manually adding component fields at the desired field points.

2. This program is appropriate for simple or in-the-field applications. However, it is quite slow, taking approximately 20 seconds per body vertex for each field point calculation. Therefore, even moderately complicated bodies will take several minutes calculating time per field point. (Plan something else to do during the waiting intervals!) Clearly, complex or multi-body problems are better handled on a more time-efficient computer system.

3. When using the profile option (step 5), the program will pause right after R/S is pressed (step 6) with the incremented X value in display. This feature is for the convenience of users who have no print cradle. The current field point can also be recovered--after the Δg calculation has run to completion--by pressing "RCL 48" (display shows X) and "RCL 49" (display shows Z).

4. The X-profile option easily may be modified to a Z-profile option (for example, for drill hole calculations) by making the following changes:

   a. Change "SUM 48" (in address 483 and 484) to "SUM 49".
   b. Insert "Pause" after address 490.
   c. Delete "Pause" command at address 487.

   At instruction step 5, ΔZ is then entered in place of the current ΔX.

TITLE GRAVITY: 2-D Anomaly PAGE 5 OF 9 TI Programmable Coding Form

PROGRAMMER _____ DATE _____

LOC	CODE	KEY	COMMENTS
000	76	LBL	Fcn A:
001	11	A	
002	42	STO	Mult. input
003	02	02	Δρ by
004	65	×	2G and
005	02	2	store
006	65	×	product.
007	06	6	
008	93	.	
009	06	6	
010	07	7	
011	03	3	
012	95	=	
013	42	STO	
014	03	03	
015	22	INV	
016	87	IFF	
017	00	00	
018	68	NOP	
019	65	×	
020	93	.	Fix-up
021	03	3	in case
022	00	0	input
023	04	4	distances
024	08	8	will be
025	95	=	in Kft.
026	42	STO	
027	03	03	
028	76	LBL	
029	68	NOP	
030	69	OP	
031	00	00	
032	07	7	
033	05	5	
034	00	0	
035	00	0	
036	01	1	
037	06	6	
038	01	1	
039	07	7	
040	69	OP	Print
041	01	01	"Δ DENSITY"
042	03	3	
043	01	1	
044	03	3	
045	06	6	
046	02	2	(These steps
047	04	4	may be
048	03	3	omitted
049	07	7	if you
050	04	4	don't have
051	05	5	a print
052	69	OP	cradle)
053	02	02	
054	69	OP	

LOC	CODE	KEY	COMMENTS
055	05	05	
056	69	OP	
057	00	00	—
058	43	RCL	
059	02	02	Print Δρ
060	99	PRT	
061	91	R/S	
062	76	LBL	Fcn D':
063	19	D'	
064	32	X:T	
065	01	1	If i=1,
066	22	INV	zero the
067	67	EQ	body pt
068	79	$\bar{x}$	counter.
069	42	STO	
070	01	01	
071	76	LBL	
072	79	$\bar{x}$	
073	32	X:T	
074	65	×	Convert
075	02	2	bodpt
076	85	+	index i
077	01	1	to storage
078	95	=	index j.
079	42	STO	
080	00	00	
081	69	OP	Decrement
082	31	31	bodpt reg.
083	76	LBL	
084	91	R/S	R/S:
085	43	RCL	Display
086	01	01	i or
087	98	ADV	n-1.
088	91	R/S	
089	76	LBL	Fcn D:
090	14	D	
091	71	SBR	Temp. store
092	45	Y×	x_i, z_i
093	53	(	
094	43	RCL	
095	00	00	
096	75	-	
097	01	1	
098	54	)	Calc. i
099	55	÷	from j.
100	02	2	
101	95	=	
102	32	X:T	
103	01	1	Check for
104	09	9	too many
105	32	X:T	bodpts.
106	77	GE	
107	77	GE	
108	71	SBR	Get TI print
109	80	GRD	code for i

LOC	CODE	KEY	COMMENTS
110	85	+	
111	01	1	
112	95	=	
113	69	OP	
114	03	03	
115	01	1	Print
116	04	4	"BODY
117	03	3	PT. i"
118	02	2	
119	01	1	
120	06	6	
121	04	4	
122	05	5	
123	69	OP	
124	01	01	(These steps
125	03	3	may be
126	03	3	omitted if
127	03	3	you have
128	07	7	no print
129	04	4	cradle.)
130	00	0	
131	69	OP	
132	02	02	
133	69	OP	
134	05	05	
135	69	OP	
136	21	21	Print
137	43	RCL	x_i
138	48	48	z_i
139	99	PRT	
140	69	OP	
141	20	20	
142	72	ST*	and
143	00	00	
144	69	OP	
145	20	20	Store
146	43	RCL	x_i
147	49	49	z_i
148	99	PRT	
149	72	ST*·	
150	00	00	
151	61	GTO	
152	91	R/S	
153	76	LBL	Y^x:
154	45	Y×	
155	32	X:T	Subr. for
156	42	STO	temp.
157	48	48	storage
158	32	X:T	of x, z
159	42	STO	pairs.

MERGED CODES

62 Pgm Lbl	72 STO Ind	83 GTO Ind
63 Int Ind	73 RCL Ind	84 Σ+ Ind
64 Pct Lbl	74 SUM Ind	92 INV SBR

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE GRAVITY: 2-D Anomaly PAGE 6 OF 9

PROGRAMMER _____ DATE _____

TI Programmable **Coding Form**

LOC	CODE	KEY	COMMENTS
160	49	49	
161	69	□P	
162	00	00	
163	92	RTN	
164	76	LBL	GE:
165	77	GE	
166	03	3	Display flashing "18." for >18 input bodpts.
167	02	2	
168	04	4	
169	94	+/-	
170	34	ΠX	
171	95	=	
172	91	R/S	
173	76	LBL	Grd:
174	80	GRD	
175	32	X:T	Find TI print code for bodpt index i.
176	09	9	
177	32	X:T	
178	67	EQ	
179	60	DEG	
180	77	GE	
181	70	RAD	
182	92	RTN	
183	76	LBL	Rad:
184	70	RAD	
185	85	+	TI print codes for 10, 11, ... 17, 18.
186	01	1	
187	09	9	
188	00	0	
189	95	=	
190	92	RTN	
191	76	LBL	Deg:
192	60	DEG	TI print code for "9"
193	01	1	
194	01	1	
195	92	RTN	
196	76	LBL	Fcn E':
197	10	E'	
198	42	STO	Store ΔX.
199	40	40	
200	91	R/S	
201	76	LBL	Fcn E:
202	15	E	
203	71	SBR	Temp. store X, Z
204	45	YX	
205	60	DEG	
206	25	CLR	Zero ΣΔF' register
207	42	STO	
208	42	42	
209	02	2	
210	01	1	
211	02	2	
212	04	4	
213	01	1	
214	07	7	

LOC	CODE	KEY	COMMENTS
215	02	2	Print "FIELD PT." (These steps may be omitted if you have no print cradle...)
216	07	7	
217	69	□P	
218	01	01	
219	01	1	
220	06	6	
221	00	0	
222	00	0	
223	03	3	
224	03	3	
225	03	3	
226	07	7	
227	04	4	
228	00	0	
229	69	□P	
230	02	02	
231	69	□P	
232	05	05	
233	43	RCL	Echo print X Z
234	48	48	
235	99	PRT	
236	43	RCL	
237	49	49	
238	99	PRT	
239	03	3	
240	42	STO	
241	00	00	
242	76	LBL	Sum:
243	44	SUM	
244	69	□F	
245	20	20	
246	43	RCL	
247	48	48	
248	94	+/-	
249	74	SM*	
250	00	00	Shift working origin to this field point...
251	69	□P	
252	20	20	
253	43	RCL	
254	49	49	
255	94	+/-	
256	74	SM*	
257	00	00	
258	97	DSZ	
259	01	01	
260	44	SUM	
261	71	SBR	
262	59	INT	
263	04	4	
264	42	STO	
265	00	00	
266	76	LBL	DSZ: main Loop Entry
267	97	DSZ	
268	71	SBR	
269	49	PRD	Restore loop reg.

LOC	CODE	KEY	COMMENTS
270	01	1	Test if i+1st vertex equals 1st vertex
271	32	X:T	
272	43	RCL	
273	01	01	
274	22	INV	
275	67	EQ	
276	28	LOG	
277	43	RCL	
278	04	04	
279	75	-	
280	73	RC*	
281	00	00	
282	95	=	
283	42	STO	
284	47	47	
285	69	□P	Calculate $a_i(x)$, $a_i(z)$, and b_i, using 1st vertex as i+1st vertex
286	20	20	
287	43	RCL	
288	05	05	
289	75	-	
290	73	RC*	
291	00	00	
292	95	=	
293	42	STO	
294	46	46	
295	43	RCL	
296	04	04	
297	94	+/-	
298	65	×	
299	73	RC*	
300	00	00	
301	95	=	
302	42	STO	
303	45	45	
304	69	□P	
305	30	30	
306	43	RCL	
307	05	05	
308	65	×	
309	73	RC*	
310	00	00	
311	95	=	
312	44	SUM	
313	45	45	
314	76	LBL	Log:
315	28	LOG	
316	70	RAD	
317	73	RC*	
318	00	00	
319	32	X:T	

MERGED CODES

62 [Tan] [Int] 72 [STO] [Int] 83 [GTO] [Int]
63 [Sin] [Int] 73 [RCL] [Int] 84 [Σ] [Int]
64 [Tri] [Int] 74 [SUM] [Int] 92 [INV] [SBR]

TEXAS INSTRUMENTS INCORPORATED

TI-24181

TITLE GRAVITY: 2-D Anomaly PAGE 7 OF 9 TI Programmable Coding Form

PROGRAMMER _____ DATE _____

LOC	CODE	KEY	COMMENTS
320	69	□P	
321	20	20	
322	73	RC*	Recall coords. for calc. of $\Delta\theta_i$, R_{i+1}/R_i
323	00	00	
324	22	INV	
325	37	P/R	
326	42	STO	
327	44	44	
328	32	X↕T	
329	35	1/X	
330	42	STO	
331	43	43	
332	69	□P	
333	20	20	
334	01	1	Test if $i+1^{st}$ vertex equals 1^{st} vertex
335	32	X↕T	
336	43	RCL	
337	01	01	
338	67	EQ	
339	32	X↕T	
340	73	RC*	
341	00	00	
342	32	X↕T	
343	69	□P	
344	20	20	
345	73	RC*	
346	00	00	
347	61	GTO	
348	69	□P	
349	76	LBL	X→t:
350	32	X↕T	
351	43	RCL	Use x_i, z_i as $i+1^{st}$ vertex
352	04	04	
353	32	X↕T	
354	43	RCL	
355	05	05	
356	76	LBL	Op:
357	69	□P	
358	22	INV	Convert to polar: Get $\Delta\theta_i$ and R_{i+1}/R_i
359	37	P/R	
360	42	STO	
361	41	41	
362	32	X↕T	
363	49	PRD	
364	43	43	
365	69	□P	
366	30	30	
367	29	CP	
368	43	RCL	
369	44	44	
370	77	GE	
371	89	π	
372	85	+	
373	02	2	
374	65	×	
375	89	π	
376	95	=	
377	42	STO	Test range of θ_{i+1}, θ_i and convert to $\Delta\theta_i$ if necessary.
378	44	44	
379	76	LBL	
380	89	π	
381	43	RCL	
382	41	41	
383	77	GE	
384	88	DMS	
385	85	+	
386	02	2	
387	65	×	
388	89	π	
389	95	=	
390	76	LBL	
391	88	DMS	
392	22	INV	
393	44	SUM	
394	44	44	
395	53	(	
396	43	RCL	
397	46	46	
398	65	×	
399	43	RCL	
400	43	43	
401	23	LNX	
402	85	+	
403	43	RCL	
404	47	47	
405	65	×	
406	43	RCL	Calc. Δg_i
407	44	44	
408	54	)	
409	65	×	
410	43	RCL	
411	45	45	
412	55	÷	
413	53	(	
414	43	RCL	
415	47	47	
416	33	X^2	
417	85	+	
418	43	RCL	
419	46	46	
420	33	X^2	
421	54	)	
422	65	×	
423	43	RCL	
424	03	03	
425	95	=	
426	44	SUM	
427	42	42	
428	97	DSZ	Is loop done?
429	01	01	
430	97	DSZ	
431	71	SBR	Restore loop reg.
432	59	INT	
433	03	3	
434	42	STO	
435	00	00	
436	76	LBL	
437	78	Σ+	Σ+:
438	69	□P	
439	20	20	
440	43	RCL	
441	48	48	
442	74	SM*	Shift origin back to starting position.
443	00	00	
444	69	□P	
445	20	20	
446	43	RCL	
447	49	49	
448	74	SM*	
449	00	00	
450	97	DSZ	
451	01	01	
452	78	Σ+	
453	71	SBR	Restore loop reg.
454	59	INT	
455	03	3	
456	00	0	
457	02	2	Print "MGAL"
458	02	2	
459	01	1	
460	03	3	
461	02	2	
462	07	7	
463	69	□P	
464	04	04	
465	43	RCL	
466	42	42	Print & display Δg.
467	69	□P	
468	06	06	
469	98	ADV	
470	91	R/S	
471	43	RCL	
472	40	40	
473	44	SUM	Increment ΔX for profile calc.
474	48	48	
475	43	RCL	
476	48	48	
477	66	PAU	
478	32	X↕T	
479	43	RCL	

MERGED CODES

62 [Pgm] [31]	72 [STO] [34]	83 [GTO] [41]
63 [LBL] [76]	73 [RCL] [43]	84 [0] [00]
64 [Pgm] [61]	74 [SUM] [44]	92 [INV] [SBR]

TEXAS INSTRUMENTS INCORPORATED

TI-24151

TITLE GRAVITY: 2-D Anomaly PAGE 8 OF 9 TI Programmable Coding Form

PROGRAMMER _____ DATE _____

LOC	CODE	KEY	COMMENTS
480	49	49	Restart
481	61	GT□	calc. at
482	15	E	entry E.
483	76	LBL	Int:
484	59	INT	
485	53	(	
486	53	(	Subroutine
487	43	RCL	to restore
488	00	00	loop reg
489	75	-	i.
490	03	3	
491	54	)	
492	55	÷	
493	02	2	
494	54	)	
495	42	STO	
496	01	01	
497	92	RTN	
498	76	LBL	Prd:
499	49	PRD	
500	73	RC*	
501	00	00	
502	94	+/-	
503	42	STO	
504	47	47	Subroutine
505	69	OP	
506	20	20	to calc.
507	73	RC*	
508	00	00	b_i,
509	94	+/-	
510	42	STO	$a_i(x)$,
511	46	46	
512	42	STO	and
513	45	45	
514	69	OP	$a_i(z)$,
515	20	20	
516	73	RC*	when
517	00	00	
518	44	SUM	vertex is
519	47	47	
520	49	PRD	not 1st
521	45	45	
522	69	OP	vertex..
523	20	20	
524	73	RC*	
525	00	00	
526	44	SUM	
527	46	46	
528	69	OP	
529	30	30	
530	69	OP	
531	30	30	
532	69	OP	
533	30	30	
534	65	×	
535	73	RC*	
536	00	00	
537	95	=	
538	44	SUM	
539	45	45	
540	92	RTN	
541	00	0	
542	00	0	
543	00	0	
544	00	0	
545	00	0	
546	00	0	
547	00	0	
548	00	0	
549	00	0	
550	00	0	
551	00	0	
552	00	0	
553	00	0	
554	00	0	
555	00	0	
556	00	0	
557	00	0	
558	00	0	
559	00	0	

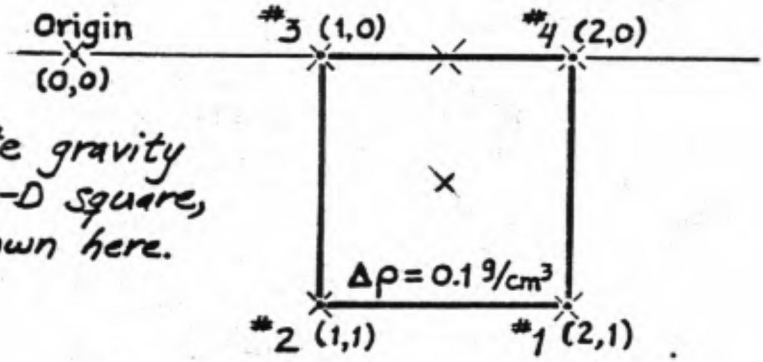
MERGED CODES

62 [Pgm] [A]	72 [STO] [A]	83 [GTO] [A]
63 [Lrn] [B]	73 [RCL] [B]	84 [B] [B]
64 [Pgm] [B]	74 [SUM] [B]	92 [INV] [SBR]

TEXAS INSTRUMENTS INCORPORATED

TI-24151

EXAMPLE: Investigate gravity anomaly due to the 2-D square, 1-Km on a side, shown here.



VARIABLE	KEY	DISPLAY	PRINT-OUT
$\Delta\rho = 0.1$ (g/cm³)	2nd A	0.1	DENSITY 0.1
$k = 1$	2nd D	0.	
$x_1 = 2$ (Km)	x↔t	(0.)	BODY PT. 1 2.
$z_1 = 1$	D	1.	1.
$x_2 = 1$	x↔t	(9.)	
$z_2 = 1$	D	2.	BODY PT. 2 1.
$x_3 = 1$	x↔t	(9.)	1.
$z_3 = 0$	D	3.	
$x_4 = 2$	x↔t	(9.)	BODY PT. 3 1.
$z_4 = 0$	D	4.	0.
$X = 0$ (Km)	x↔t	(9.)	BODY PT. 4
$Z = 0$	E	$\Delta g = .2646785599$ mgal	2. 0.
$X = 1$	x↔t	(0.)	
$Z = 0$	E	$\Delta g = 1.510729502$ mgal	FIELD PT. 0.
$X = 1.5$	x↔t	(0.)	0.
$Z = 0$	E	$\Delta g = 2.311546117$ mgal	.2646785599 MGAL
$X = 2$	x↔t	(0.)	
$Z = 0$	E	$\Delta g = 1.510729502$ mgal (flashing)	FIELD PT. 1.
Because error is possible when field points are at first or last body vertex, display flashes and "?" appears on print-out. Here, answer is a.k. by symmetry considerations, however. To clear flashing, press "CLR".			0. 1.510729502 MGAL
			FIELD PT. 1.5
$X = 2$	x↔t	(0.)	0. 2.311546117 MGAL
$Z = 1$	E	$\Delta g = -1.510729502$ mgal (flashing)	
			FIELD PT. 2.
	CLR	0.	0. 1.510729502 ?MGAL
$X = 1$	x↔t	(0.)	
$Z = 1$	E	$\Delta g = -1.510729502$ mgal	FIELD PT. 2.
$X = 1.5$	x↔t	(0.)	1. -1.510729502 ?MGAL
$Z = 0.5$	E	-1.60057 -12 mgal	
By symmetry, the correct answer is zero at this point. Round-off error has led to a very small number being output here.			FIELD PT. 1.
			1. -1.510729502 MGAL
			FIELD PT. 1.5
			0.5 -1.60057-12 MGAL