FINAL REPORT TO CMHC OF THE MULTI-POINT SPACE FRAME FOUNDATION MONITORING AND ANALYSIS

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OF THE

MULTI-POINT SPACE FRAME FOUNDATION MONITORING AND ANALYSIS

Prepared For:
Project Implementation Division
Canada Mortgage & Housing Corporation

By:

Reid Crowther & Partners Limited
Edmonton, Alberta

Principal Consultant: J.A. Isenegger, P.Eng.
CMHC Project Manager: R.L. Duncan, P.Eng.

March, 1989

Reid Crowther

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Reid Crowther

1.0 EXECUTIVE SUMMARY

The Arctic provides a challenging environment for foundation designs - usually two completely different set of factors for winter and summer conditions.

- Winter will have maximum snow and wind loads together with frozen ground that while it provides the best rigid foundation support also causes uneven upward movement of the structure due to frost heave and jacking.

- In summer the opposite conditions could prevail - a semi-permanent permafrost having very poor load bearing capacity and spongy support due to thawing of the frozen soil.

Design and construction without consideration of these factors is the primary reason for most of the traditional foundation failures causing racking and structural damage.

This investigation of the performance of a multi-point space frame as an alternative to the traditional Arctic foundations is the next in a series of investigations and developments being carried out by CHMC to reduce or eliminate the foundation racking. The first being the 3-point support system carried out in 1986.

It was known theoretically at the beginning of the study that the multi-point space frame was not designed to support the house structure when large vertical settlements occur that would put the frame back to a 3-point support system. However, it was demonstrated through computer analysis and simulations, that when modified, the space frame does provide a very adequate support for year round conditions. The introduction of foam springs under the supports facilitates the redistribution of loads and relieves some

of the frost heave pressures. Interaction between the frame footings and an ideal soil with uniform materials, moisture content and spring constants will have the same load redistribution effect.

Future house designs using space frame foundations should have central wall supports to redistribute the foundation loads to the centre of the house such that all footings will have approximately the same loading initially.

Two houses supported on space frames sited in the worst foundation conditions possible, i.e. semi-permanent or discontinuous permafrost, as found in Hay River and Fort Franklin, performed well over a complete season. Uniform moisture content in the soil should minimize differential movement between footings.

In order to optimize frame member and footing sizes, further testing in a controlled environment and field monitoring of loads transferred through the members and footings with strain gauges has been recommended.

2.0 BACKGROUND

A feasibility study of space frame foundation on three point support in permafrost was carried out by Ferguson, Simek, Clark in 1986 for Canada Mortgage & Housing Corporation. The report found that the three point space frame foundation was successful in eliminating racking of the house but required heavy steel members and large footings. Further study of a multiple point supported space frame was recommended because the system would be more cost effective as it uses lighter members and smaller footings.

This report deals with the foundation field monitoring and theoretical computer analysis of the multi-point supported space frames erected for residential structures in Hay River and Fort Franklin, N.W.T.

The intent is to determine the load sharing capability of a multi-point space frame bearing on flexible supports compared to a rigid support system that theoretically would result in overstressing the soil and frame members.

3.0 INTRODUCTION

Most buildings in the North are constructed on either permafrost or semi-permafrost soils. Many foundation failures can be attributed to the lack of subsurface and site information, poor site preparation and construction methods due to shipping restrictions, severe climate and short construction season, lack of building materials and equipment and inadequate maintenance. The primary failure mechanism is excessive differential foundation movements due to permafrost degradation and/or frost heave and thawing actions in the active layer.

Conventional foundation systems common in the North include steel or timber piling, timber cribbing or shallow spread footing. All these foundation systems require some means of preventive measures to protect the permafrost from degradation such as ventilated crawl spaces, floor insulation or duct ventilated gravel pads. Any heat transferred from the building to the soil thermal regime will cause the thawing of the permafrost, the subsequent settlement of the soil and eventual damage to the structure. Usually, end bearing piles are anchored into the bedrock or other dense medium and friction piles are installed in bored holes relying on freeze-back to carry loads. However, if they are not properly designed and constructed, frost heaving or jacking of piles will be a major problem especially for lightly loaded structures.

Surface and shallow footing are also subjected to ground movement due to seasonal frost heave and thawing actions. Periodic observations and adjusting the levels as required are standard recommendations to prevent racking of the house structure. However, this maintenance procedure is seldom carried out properly. Instead, force wedging and eyelevelling are commonly used only when the occupant notes that the house structure and building envelope has been damaged as evidence by the drywall cracking and the floor sloping. This force wedging adjustment may bring the house back to the level and be visually acceptable but could also cause further damage to the house structure and envelope in the process.

Multipoint supported space frame foundation systems appears to have the potential to be a reliable, simple and relative maintenance free solution to these problems. In concept, the frame should be capable to maintain a rigid plane of support for the building by bridging over some soft spots resulting from ground settlement or by absorbing the frost heave pressure through load redistribution. However, it is not completely understood how well the frame will behave with respect to the member's rigidity, the bearing point type and the site conditions.

There was an opportunity for CMHC, RCDP, N.W.T. Housing Corp and Hay River Housing Authority to construct and test a multipoint space frame foundation for a new house in Hay River Reserve. The space frame was constructed in the fall of 1987 and the performance was monitored four times over one year. Also, the pads and wedges foundations of a duplex and two 4-plex structures in Fort Franklin, N.W.T. required strengthening and remedial work and a space frame was used for this purpose. These locations were chosen as they are located in semipermanent or discontinuous permafrost conditions. These conditions would theoretically provide the worst type of foundation base possible. In order to establish the performance of the foundation, field monitoring was to be carried out and computer analysis of various models undertaken.

This report presents the results of the field monitoring and computer analysis and recommends the most optimum frame configuration and support conditions to be used in practice.

4.0 SITE INVESTIGATION AND MONITORING

4.1 Hay River Reserve House

.1 Construction Elements

House:

- 1 storey 8.5 m wide x 14.0 m long (28' x 46') wood framed structure.
- Roof: plywood on common pitched single span timber trusses supplied by Gang Nail Canada Inc.
- Exterior Walls: prefabricated 38 m x 140 m (2x6) wall panels by Nelson Homes.
- Floor: plywood on 38 mm x 286 mm (2x12) wood joists spaced at 400 mm o.c. (16") bearing on 3 - 38 mm x 140 mm (2x6) built up beam supported by metal space frame top sill plate brackets spaced at 1980 mm (6'-6") apart.

Metal Space Frame:

- 8 m x 14 m x 1.1 m high (26' x 46' x 3'-7") metal space frame supplied by Triodetic Building Products Ltd.
- it has 242 members, 28 footings and 40 top support sill brackets arranged in a 1980 mm (6'-6") square grid pattern.
- top chords are 89 mm (3 1/2") dia x 4 mm (0.148") wall thickness aluminum alloy 6061-T6 tubes.
- bottom chords are 76 mm (3") x 4 mm (0.148") wall thickness alluminum alloy 6061-T6 tubes.
- Webs are 64 mm (2 1/2") dia. x 4 mm (0.148") wall thickness galvanized steel tubes.
- all tubes have flattened end plugs.

- connections are aluminum alloy formed hubs with single through bolt and washers.
- footings are 300 mm x 300 mm x 20 mm thick (12" x 12" x 3/4") steel bearing plates.

.2 General Construction Progress to date:

The multi-point space frame foundation was erected in the fall of 1987 and the house interior finishes completed by early 1988.

.3 Foundation Monitoring:

- Initial assessment of the site conditions and elevation check of the space frame foundation was carried out by Ray Chan, P.Eng. and Ian Mathers of Reid Crowther on October 7, 1987.

- A bench mark was set up at the school on steel H-piles driven to refusal. (See Appendix A). Without the house dead load on, the space frame was found to be level. For purpose of comparison, elevations were also taken for the nearby houses on steel pipe pile foundations, since these pipe piles were relatively short and subjected to frost heave and thaw actions. The change in the elevations measured, as shown in Appendix C, confirm the movement and the soil behaviour in the area.

- A re-survey of the space frame foundation was carried out on December 9, 1987, March 30, 1988 and July 6, 1988. (December 9, 1987 measurement are not related to the benchmark because of the unexpected field conditions). The results show that the space frame has displaced upward in the winter by an average of 21 mm with a minimum movement of 3 mm and a maximum of 29 mm. In the spring, the space frame settled by an average of 19 mm with a minimum movement of 2 mm and a maximum of 37 mm. The graphs in sketches SK 4.1 and 4.2 show the relative displacement along each grid line. It appeared that there was more frost heaving and thawing at the southeast portion of the structure where the compacted driveway might have prevented water drainage.

- A geotechnical evaluation of the bearing soil and site conditions was made by Garry Hollingshead, P.Eng. of Thurber Consultants Ltd. (See Appendix E). Maximum foundation movement is expected during the spring thaw. Field monitoring was recommended to be scheduled immediately before and after spring thaw.

.4 Observations

From discussions with the contractor, Jim Sawka, a review of the space frame foundation on site and the video tape recording of the construction, we have noted the following:

.1 Engineering/Technical

- The total design live and dead loads of the house and space frame was about 6.7 kn/sq.m. (140 psf). The actual loading used was 4.3 kn/sq.m. for winter loads and 2.3 kn/sq.m. for summer loads.

- Based on the design loading, the pressure on individual 300 x 300 footings of about 240 kPa (5000 psf) appeared to be very high with respect to the estimated allowable bearing pressure of 50 kPa (1050 p.sf).

Based on the number, relative low costs and problems of the recently built pile and wood crib foundations in the area, there exists a potential market for the multipoint space frame foundation in the housing industry as long as it can be shown to effectively resist racking and be cost effective.

.2 Cost

- Capital cost of the multipoint space frame foundation Hay River reserve was about $15,200.00 which included $10,000.00 for materials, $2,000.00 for labour, $2,000.00 for transportation costs and $1,200.00 for built-up beams. This would compare to foundation costs of about $12,000.00 for piled foundations and $5,000.00 for crib foundations. (See Appendix G for cost comparisons).
- There will be minimal annual maintenance costs for level adjustments.
- Extra spare parts were provided during construction and replacement parts are readily available from the manufacturer.
- "Moduspan" by Unistrut and "Isoframe" by Artecal are two competitors of the Triodedic space frame used. (see Appendix J for details).

.3 Construction/Expediting

- The multipoint space frame members are relatively light (approx. 15# for aluminum and 30# for steel) and readily shipped and handled during construction.
- The erection of the 68 joints and 242 members space frame took three unskilled labours and one manufacturer representative three days to complete.
- The hub slots, member size and plugs were all precision made in the factory with minimal variety that simplified and facilitated the erection process.
- The manual wench was replaced with power wench during construction to facilitate tightening of the hubs.
- A specially made leather head hammer was used to force both ends of the tube member simultaneously into the hub slots. WD40 was used as a lubricant for the hub slots.
- Three panels of the erected frame were manually lifted without racking to allow footing level adjustment.
- The house edge beam orientation was discussed and it was decided it would be placed upright on the top bracket. Holes were provided in the brackets for nailing. However, no nails were found to be installed during the March, 1988 site visit. The house and the frame can therefore move somewhat independently, as there is little physical connection between them and the wall stiffeners is not contributing to the frame stiffness especially during settlements.

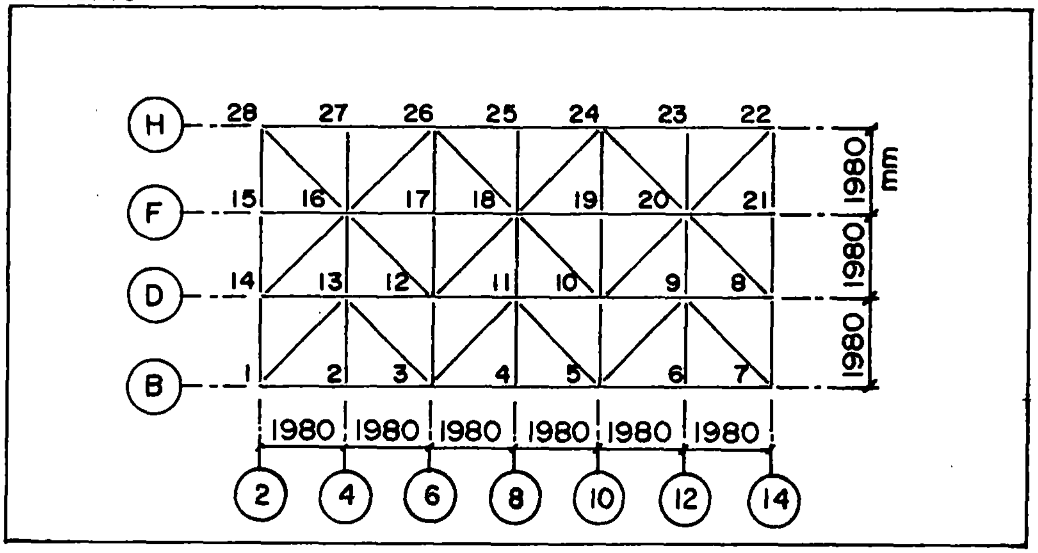
.4 Impact/Integration

- There was less disturbance to permafrost, soil and environment using a space frame than installing pile foundations.
- After the monitoring is complete, a skirt will be installed around the space frame that will make the house look similar to those in the neighborhood.
- The local unskilled labourers appeared very eager to learn the new construction techniques and were able to put it together with some guidance.

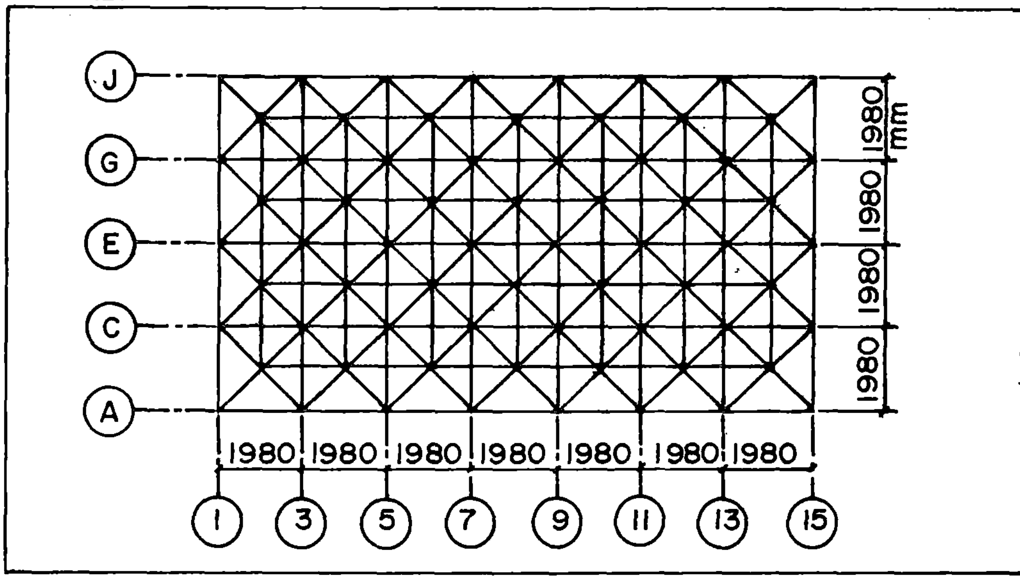
.5 Potential/Obstacles

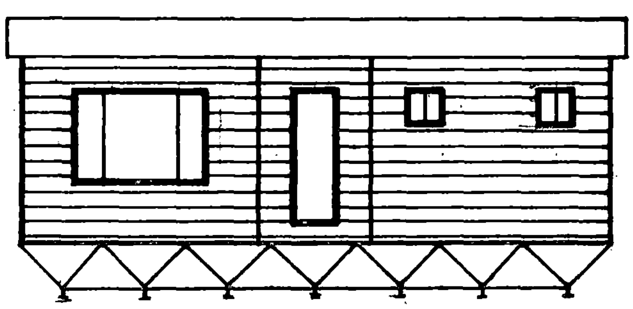
- This foundation type is appropriate for unstable soils and for remote areas where it is difficult to obtain suitable equipment, material and skilled labour for piling or site preparation for pads.
- This space frame could be modified to suit various building sizes and layouts.
- The size of members and footing details could be refined to reduce foundation stress and material costs, thereby making the frames more economical.

SUPPORTS



TOP VIEW

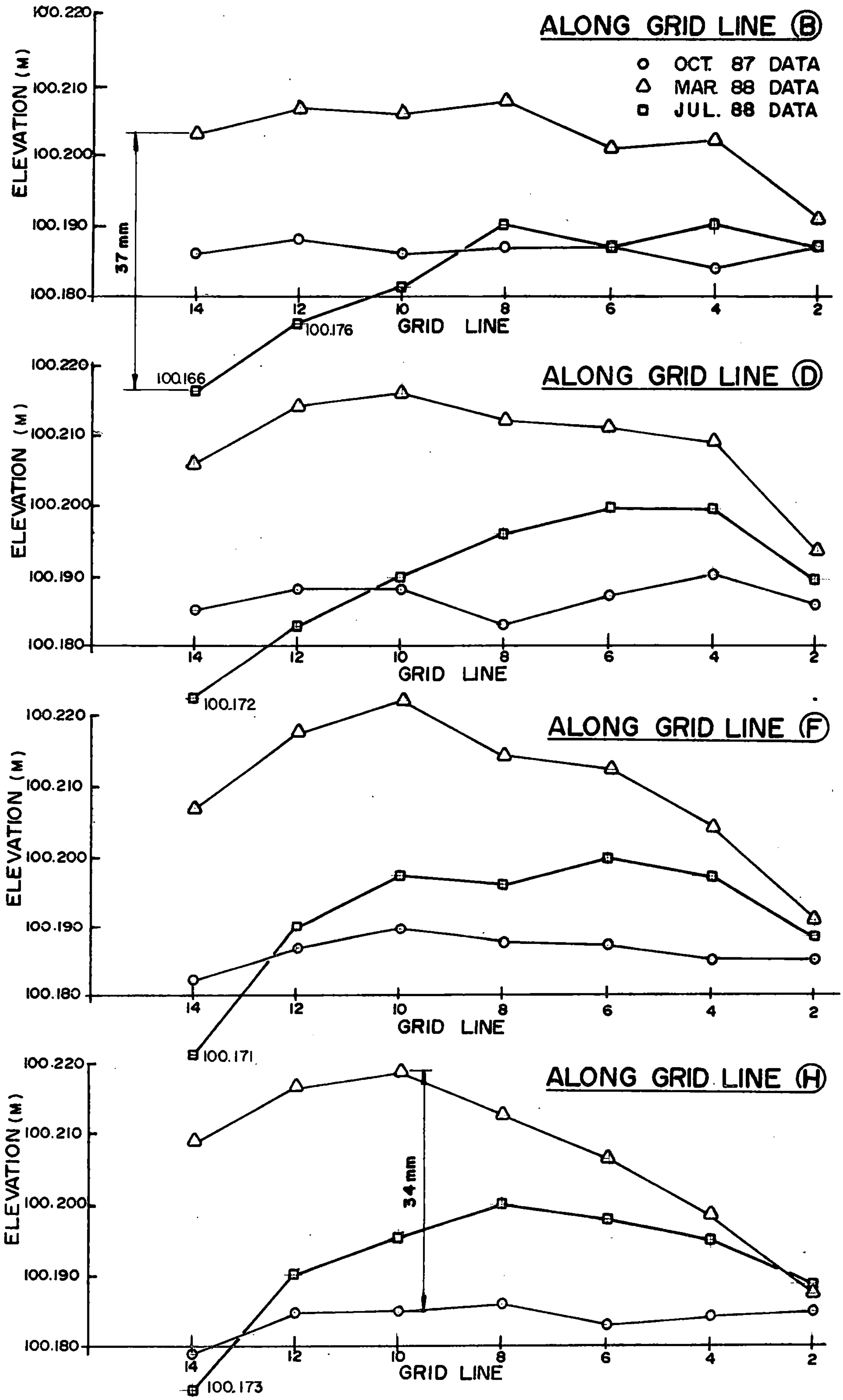




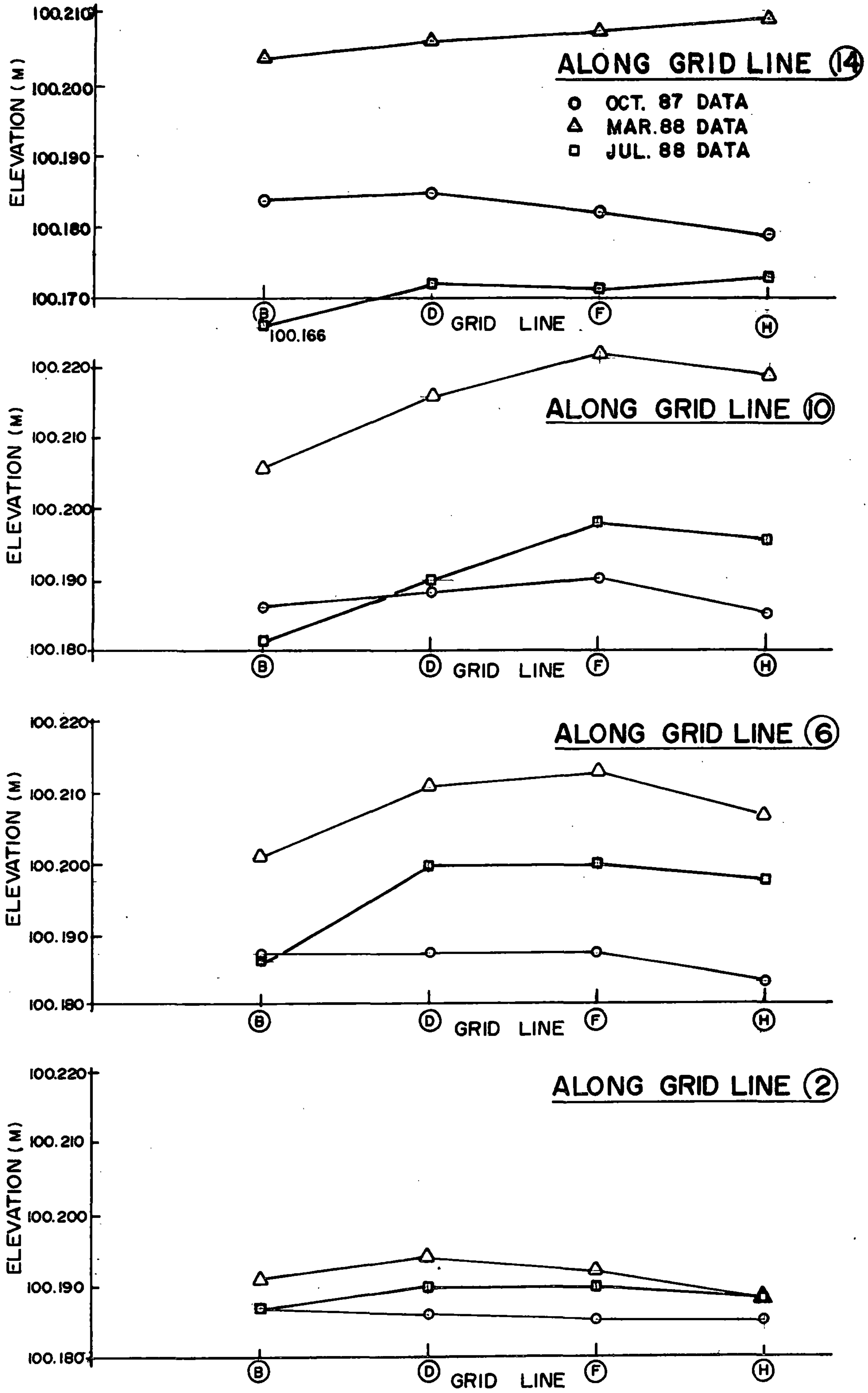
ELEVATION

HAY RIVER RESERVE
AS BUILT SPACE FRAME (No.1)

SK-4.0


ALONG GRID LINE (B)
OCT. 87 DATA
MAR. 88 DATA
JUL. 88 DATA
ELEVATION (M)
37 mm
100.176
100.166
GRID LINE
ALONG GRID LINE (D)
100.172
ALONG GRID LINE (F)
100.171
ALONG GRID LINE (H)
34 mm
100.173

SK-4.1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OCT. 87 DATA
MAR. 88 DATA
JUL. 88 DATA
ELEVATION (M)
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100.200
100.190
100.180
100.170
100.166
B
D
F
H
GRID LINE
ALONG GRID LINE (10)
ELEVATION (M)
100.220
100.210
100.200
100.190
100.180
GRID LINE
ALONG GRID LINE (6)
ELEVATION (M)
100.220
100.210
100.200
100.190
100.180
GRID LINE
ALONG GRID LINE (2)
ELEVATION (M)
100.220
100.210
100.200
100.190
100.180
GRID LINE

SK-4.2

4.2 Fort Franklin - Duplex and 4-Plex

.1 Construction Elements

Houses:

- one 2 storey 6.7 m wide x 18.3 m long (22' x 60') duplex and two single storey 11.6 m wide x 19.5 m long (38' x 64') 4-plex.
- wood framed structures with heavy glu-laminated floor beams.
- one year old and unoccupied.
- wood crib foundation failed and caused excessive damages to the house structure and finishes.

Metal Space Frame:

- space frame was used to reinforce the crib foundation.
- 1 m (3') high metal space frame supplied by Triodetic Building Products Ltd.
- Top and bottom chords are 89 mm (3 1/2") dia. x 4 mm (0.148") wall thickness galvanized steel tubes.
- Webs are 60 mm (2 3/8") dia. x 4 mm (0.148") wall thickness galvanized steel tubes.
- Connectors are aluminum alloy formed hubs with single through bolt and washers.
- Connection to glu-laminated beams has double 355 mm x 300 mm x 16 mm thick (14" x 12" x 5/8") steel plates c/w 4-22 mm (7/8") dia. A307 threaded rods.
- footings are 250 mm x 250 mm x 22 mm thick (10" x 10" x 7/8") double plates with 4 adjustable A307 threaded rods.

.2 General Construction Progress to Date

- The houses were re-levelled after the installation of the space frame reinforcement.

- The houses are occupied and the space frame foundation crawl space is partially enclosed with wire-mesh skirt.

.3 Foundation Monitoring

- An elevation check was carried out on July 7, 1988, not long after the spring thaw, to record the maximum movements. The results and photos are shown in Appendix D and F, respectively.

- There were two 4-plex and one duplex which all had wood framed construction with heavy glu-laminated floor beams. The metal space frame reinforced the building foundation by having the top metal tube members connected to the sides of the glu-lam beams and a number of adjustable 10"x10" steel plate footings bearing on a thick gravel pad.

- The maximum variation of elevations at top of hubs was 8 mm. There was no evidence of cracking, separation or structural failure resulting from foundation movements.

5.0 COMPUTER MODELLING AND ANALYSIS OF HAY RIVER RESERVE HOUSE SPACE FRAME

- A computer model of the Hay River House space frame structure was set up as per the dimensions provided by the Triodetic shop drawings (see Appendix B).

- Frame member properties as per Triodetic specifications:

  Steel ES = 200,000 Mpa GS = 77,000 Mpa

  Aluminum Aloy EA = 69,000 Mpa GA = 26,000 Mpa

  Allowable Member Forces:

Type	Length (mm)	Compression (Kn)	Tension (Kn)
Top chord	1980	70	96
Bottom chord	1980	52	81
	2800	33	81
Web	2915	59	197

- Various simulations were run (see Summary)

- Foundations supported on springs were simulated using the properties of Ethafoam brand polyethylene foam bearing pads (see below).

5.1 Loads Used for Analysis

The structural analysis of the multi-joint space frame foundation was based on the design loading requirements of the National Building Code of Canada, December 1985, and its supplements.

The loading criteria used was as follows:

Use and Occupancy - Live loads	Design	Actual
	1.9 kPa	0.72 kPa
Dead Load Floor, wall and roof	Design	Actual
	1.0 kPa	0.53 kPa
space frame weight		0.43 kPa
Snow	Design	Actual
0.8 x ground snow 2.6 Kpa	2.08 kPa	0 kPa Summer
		2.0 kPa Winter
Wind		
1/30 year gust for strength design	0.32 kPa modified to NBC 85	
Seismic		
Zonal Velocity Ratio	0.05	

5.2 Factors Considered and Assumptions Made for the Frame Behavior and Foundation Support

.1 In order not to crack the drywall finishes of the house, or damage the air/vapour barrier, a maximum deflection of L/360 between any two supports was assumed. Should any bearing point fail to provide support this would amount to deflections of 11 mm between any adjacent supports and 15.6 mm between supports on the diagonal.

In order to analyse the ability of the space frame to bridge over soft spots, the supports were removed in various combinations and the results calculated.

.2 The two distinct loading and support conditions that exist in the artic were considered. During the winter months, permanent permafrost conditions will exist and maximum snow and wind loads are possible. During the summer months semi-permafrost conditions could exist with no snow or wind loads present.

Therefore in winter the permafrost could easily support large loads on small foundations. The foundations should be as small as possible to reduce the frost heave and jacking forces. On the other hand, during the summer, the footings would have to be large to be safely supported on the thawed soil with low bearing capacity. Only the actual dead loads, with small realistic live loads of furniture and of say 6 people should be considered.

A balance would have to be struck between the possible seasonal conditions. Models simulating frost heave at the end of the space frame and also permafrost melt at the ends should be analysed.

.3 Ideally the soil should behave in a uniform manner. This seldom happens unless thick granular material is present.

.4 In order to simulate the space frame bearing on a elastic foundation, springs were added at the supports. Steel springs, air bag and styrofoam bearing pads have been considered and rejected for their high costs and impracticality. Only steel plates on sand and ethafoam pads were used for further analysis.

.5 The relative elevations measured on December 9, 1987 were used as relative deflections in one of the models. Further levels were taken in March and July of 1988.

.6 The eccentric moments on the hubs due to the eccentric members have been neglected. The semi-rigid connection usually increases frame siffness. However, the understanding of its effects on the frame will require more experiment and analysis which is outside of the limit of this study.

.7 To properly reflect the forces and movements generated from the simulations, the stiffness of the frame and load distribution patterns should be considered.

Ideally the stiffness of the house framing should also be considered. The prefabricated wall panels are so rigid that they can span over some supports which may have failed. If the wall panels are properly designed and connected to the frame, the stiffness of the whole frame and house structure will definitely be increased.

.8 The loading on the frame is mainly line loading from the load bearing walls at the perimeter of the frame. The frame would have to be stiff enough to distribute the loads to the centre supports.

5.3 Summary of Computer Analysis

The computer analysis was carried out in three stages:

.1 Computer Analysis Based on Design Loadings as per NBC

- A table of the computer analysis summary based on design loadings is shown on the facing page.

  Note that the loads found exceeded the allowable member forces. They should be reduced by at least 45% to include for the actual dead loads and modified live loads to more accurately reflect the actual loadings.

- Most of the loads are live loads at the perimeter of the frame. The space frame does not appear to be rigid enough to re-distribute the loads from the edges to the interior (see Pattern 1, 6, 7, and Sketch SK-5-1). Additional or larger footings at the perimeter may be required to share the loads.

- If member forces are reduced by 45% to reflect the actual loadings, the space frame is able to bridge over one bearing point without overstressing the members. (See Pattern 3).

- Based on the zero value or low member forces, the bottom members appeared to be redundant and oversized in most loading patterns.

- Either Settlements or frost heaving of any support point may cause overstressing of the space frame members. (See Patterns 8 to 12). Placing high density styrofoam under the footing will relieve some of the frost heave stresses.

- Live loadings used as per NBC seem unrealistic. The actual weight of the house and occupancy was re-evaluated for further analysis.

- Most deflections calculated are within the recommended L/360 limit. With deflections over this limit, the frame will be overstressed and failed before damage occurs to the house. This may allow adjustments of the footing height and replacement of the damaged frame members without requiring repairs to the house.

- The heavy loads at some of the footings would exceed the estimated 50 Kpa allowable bearing pressure on the footings. Settlements most likely will occur at these footings in the spring thaw, causing a redistribution of the loads. As shown on SK-4.2, the footings along exterior grid lines B & H did settled more than the interior footings showing that part of the loads must have transferred to the interior footings.

.2 Computer Analysis Based on Actual Loadings

- The following estimated actual loadings were used:

Roof dead load	0.55 kn/sq.m (11.4 psf)
Wall dead load	0.38 kn/sq.m (8.0 psf)
Floor dead load	0.53 kn/sq.m (11.0 psf)
Floor live load	0.72 kn/sq.m (5 psf occupancy plus 10 psf household loads)

- Maximum reaction based on 300 x 300 footing and the estimated 50 Kpa allowable bearing pressure is 4.5 KN (1012 lbs). The result as shown on sketch SK-5.2 for frame No. 1 (242 members, see Sketch SK-4.0) still had very high reactions at the perimeter. The maximum load of 16.8 kn had a bearing pressure of 187 kpa (3900 psf) on the subgrade.

- A modified space frame No. 2 with additional supports at the perimeter (see sketch 5.3) but less members (234) was used to minimize the bearing pressure. The results showed that the maximum force had been reduced to 11.7 kn with bearing pressure = 130 kpa (2710 psf). (See Sketch 5.4)

.3 With Polyethylene Foam (Ethafoam 220)

- Polyethylene foam pads were introduced to provide simulated spring effects at the footings such that loads could be redistributed in conjunction with minor vertical movement. This light weight polyethylene foam pad consists of millions of closed air-filled cells. It could provide some of the frost heave compression relief without overstressing the frame members.

- For frame No. 1 with 300 mm x 300 mm x 100 mm thick Ethafoam pad, the maximum reaction was 11.2 kn (see sketch SK 5.5).

- For frame No. 2 with 300 mm x 300 mm x 100 mm thick Ethafoam pad, the maximum force was 7.6 kn (see sketch SK 5.6).

- Various spring constants and pad sizes were used in the analysis to determine the best combination of type and size of pad (see sketch SK 5.7 for result of one of the combinations).

- A pad size of 400 mm x 400 mm x 100 mm thick with spring constant of 6000 kn/m was found to be the most optimum for frame No. 2 as the maximum reaction of 8.1 kn had an equivalent bearing pressure of 50.6 kpa (1058 psf). (see sketch SK 5.8). The bearing pressure is approximately equal to the estimated allowable bearing pressure without any detrimental settlement.

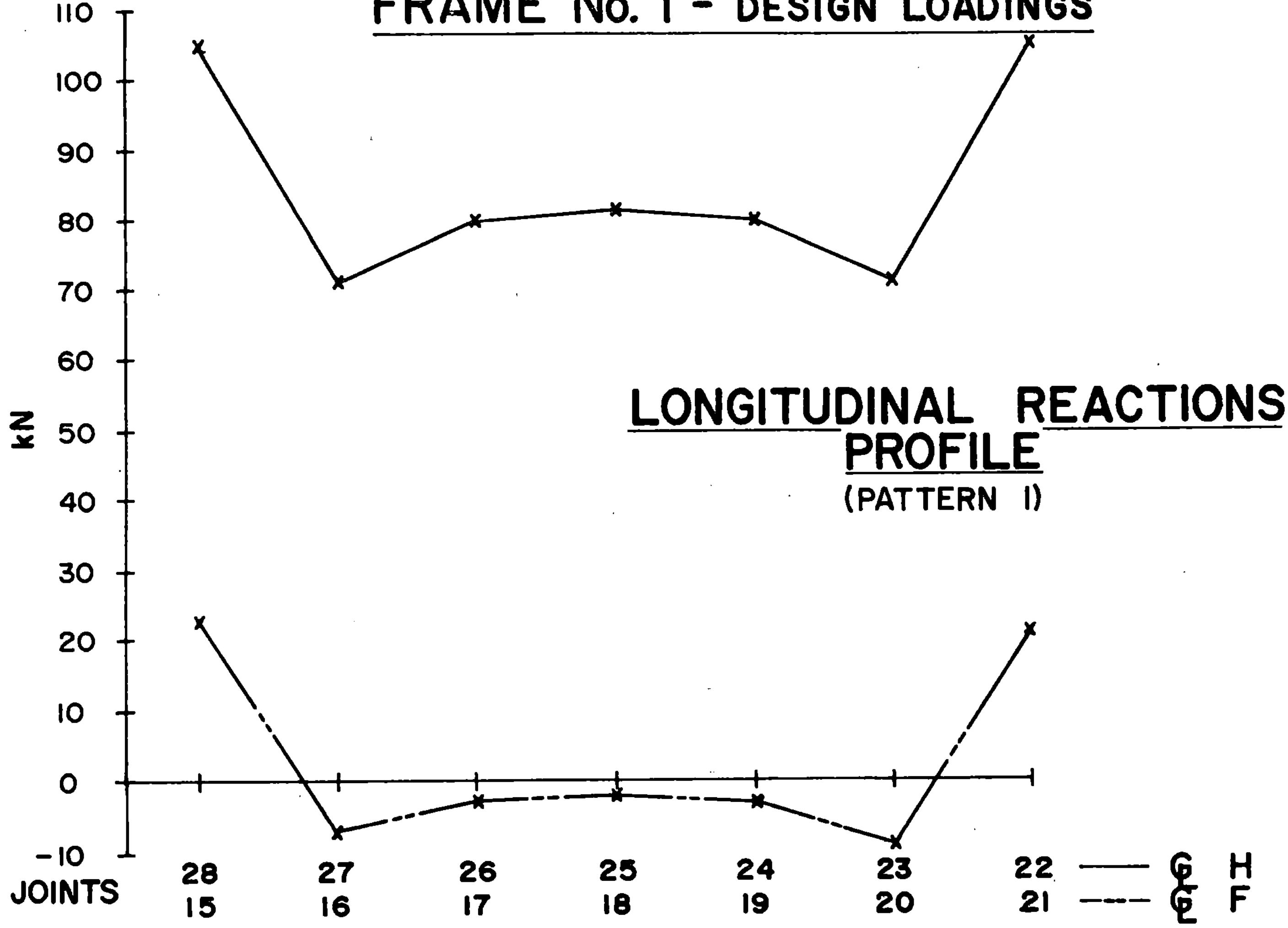
5.4 Wind Effects

The wind effects on the building in this site surrounded by tall trees is negligible. The safety factor against overturning due to lateral wind load and uplift is more than 4. In remote open terrain arctic region where high wind pressure is significant, physical tie down such as gravity or rock anchors are necessary.

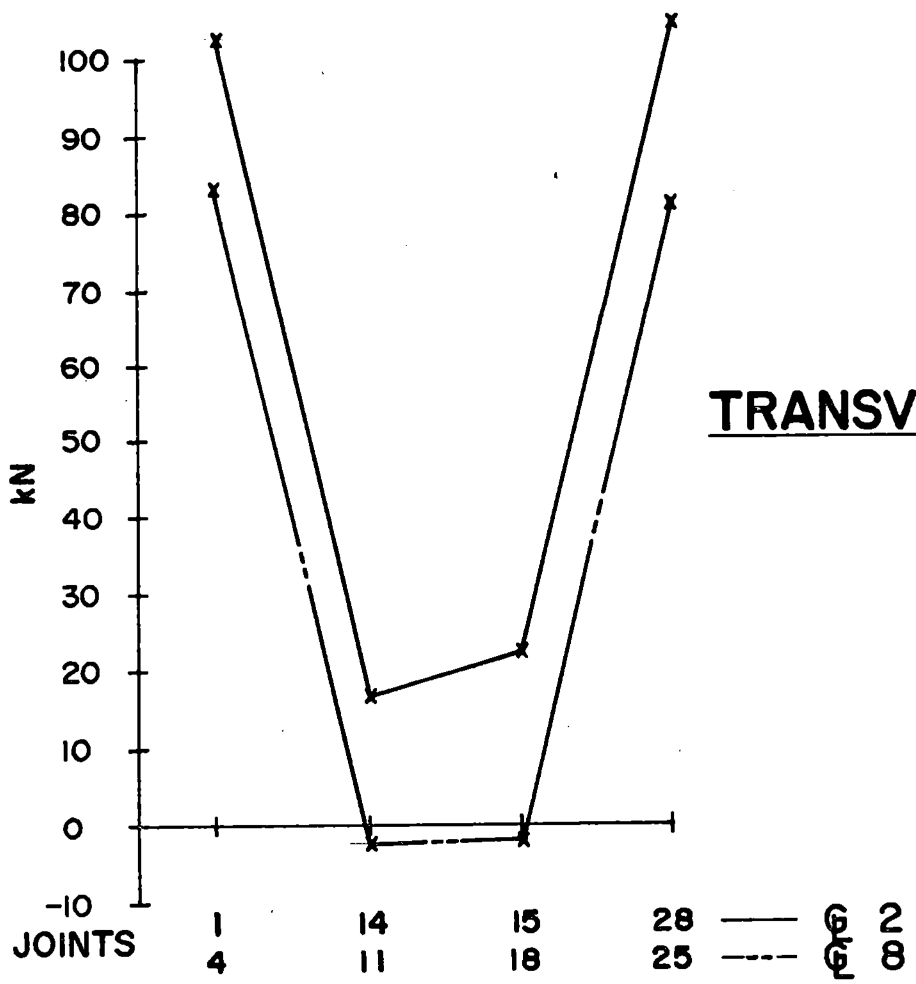
With its heavy metal density and member interlocking capabilities, the space frame will provide better stability against overturning than a traditional light weight pad and wedges footing.

Because of its light aluminium and wood framed structure, the wind forces exerted on the building are higher than the seismic forces.

FRAME No. 1 - DESIGN LOADINGS

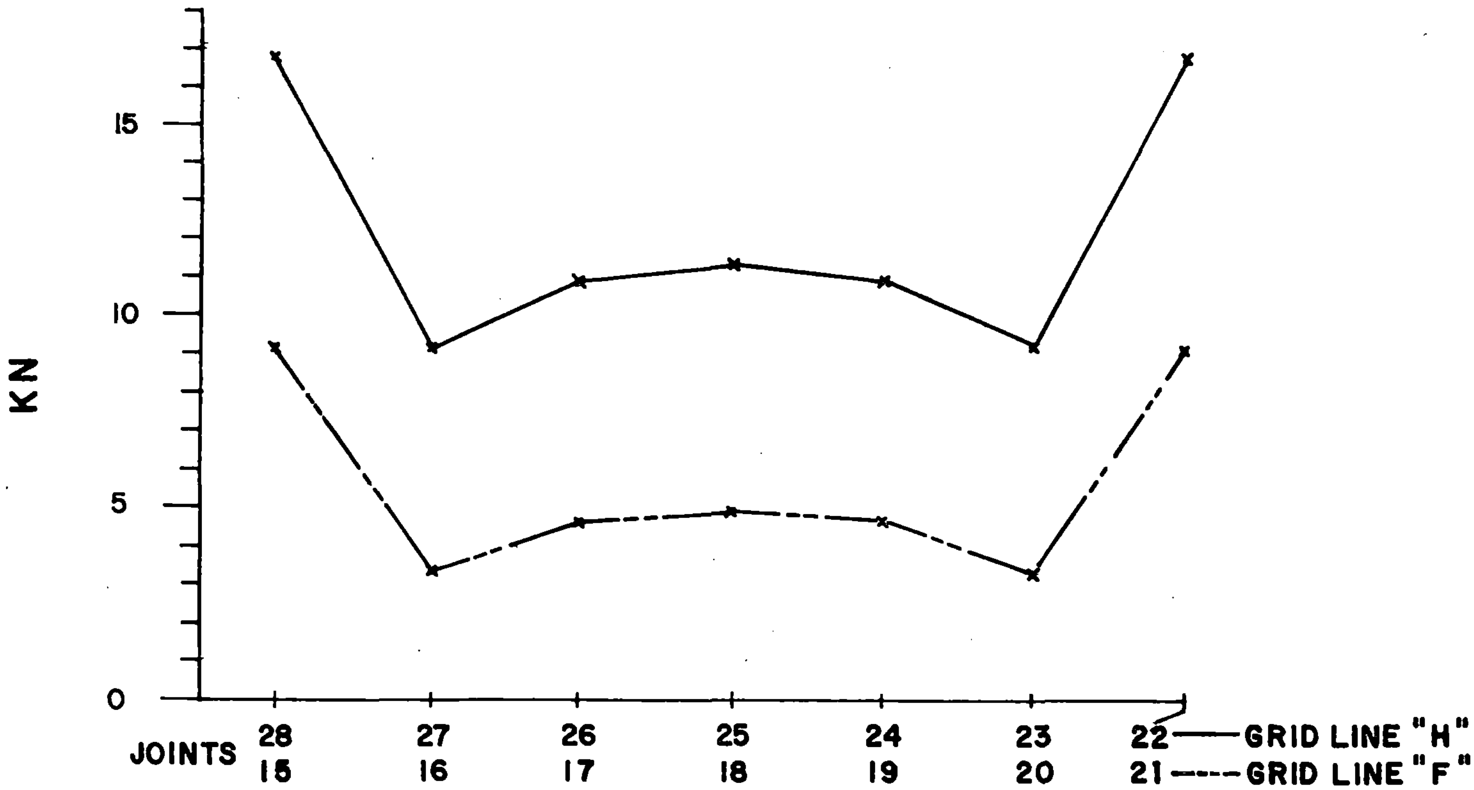


LONGITUDINAL REACTIONS PROFILE
(PATTERN 1)

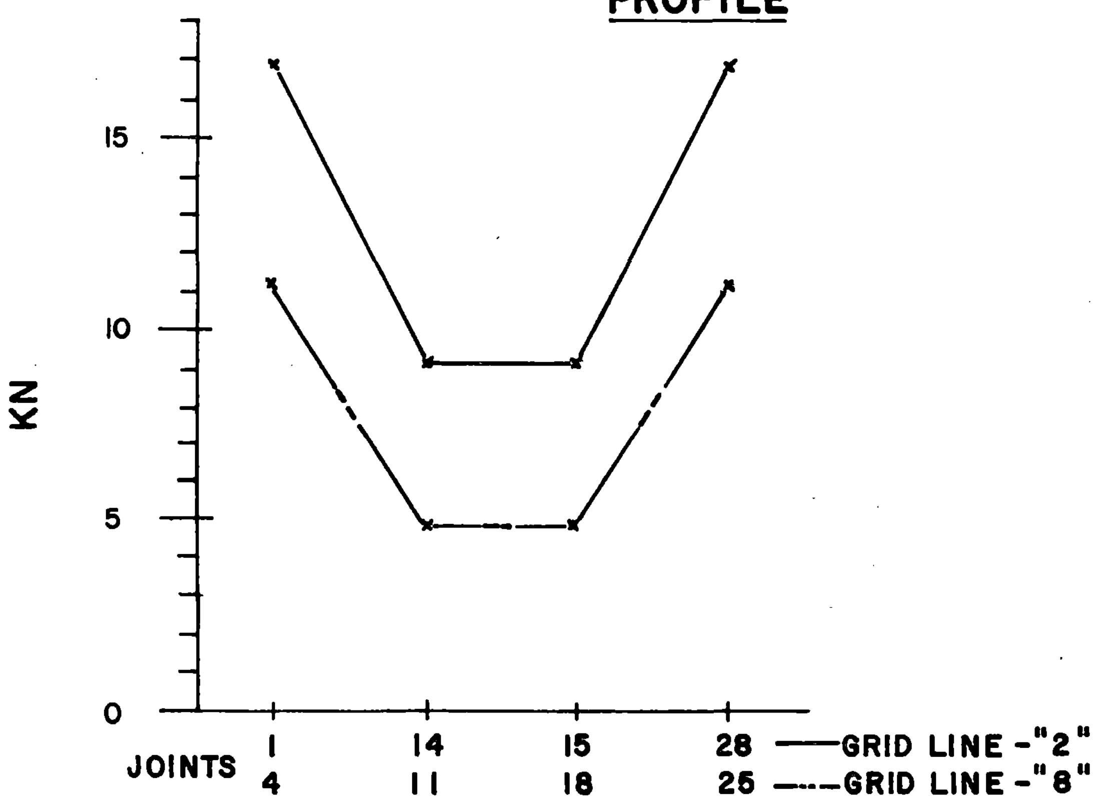


TRANSVERSE REACTIONS PROFILE
(PATTERN 1)

SK-5.1



LONGITUDINAL REACTIONS PROFILE

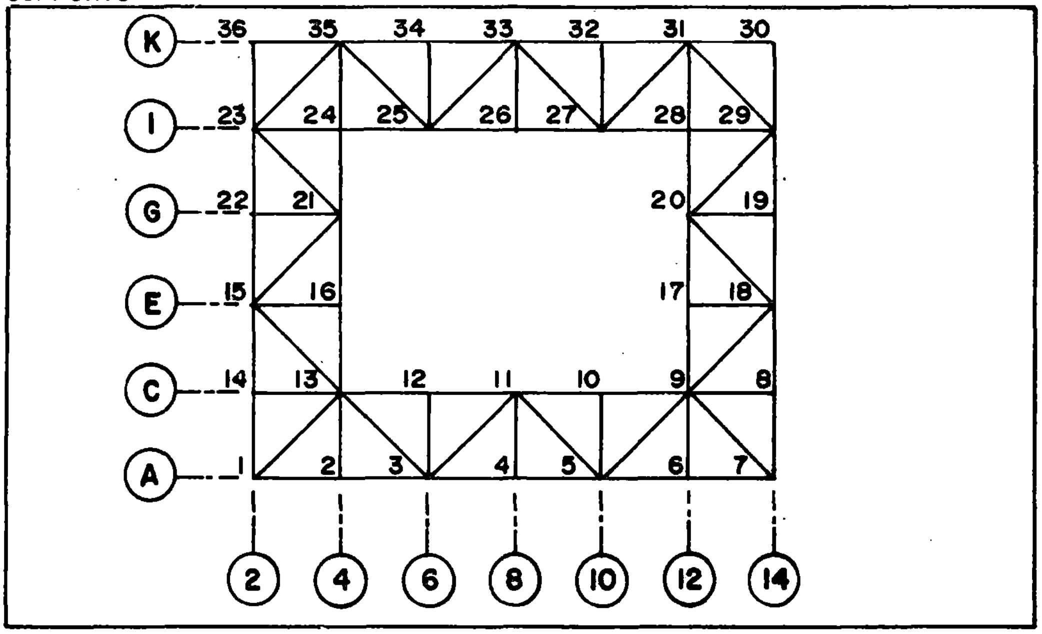


TRANSVERSE REACTIONS PROFILE

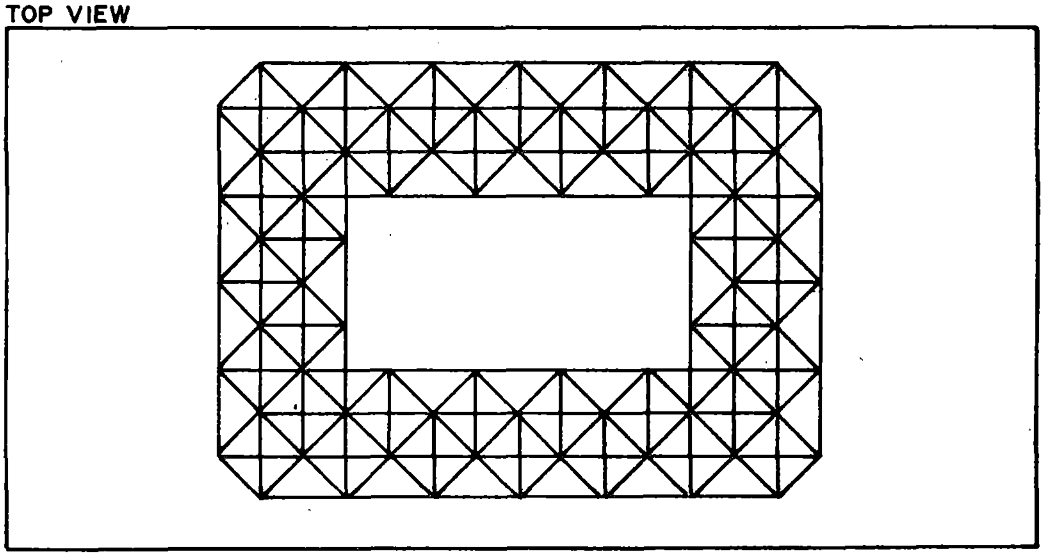
FRAME No. 1 - ACTUAL LOADING

SK-5.2

SUPPORTS



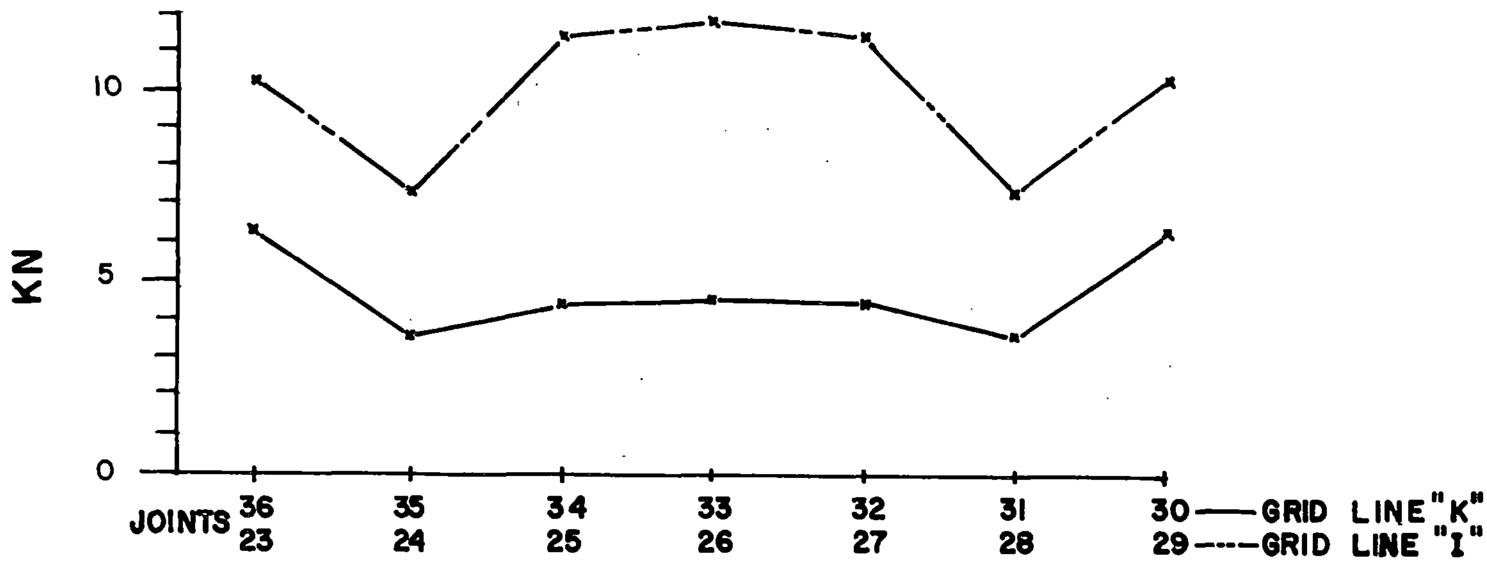
TOP VIEW



HAY RIVER RESERVE
MODIFIED SPACE FRAME

FRAME No. 2

SK-5.3



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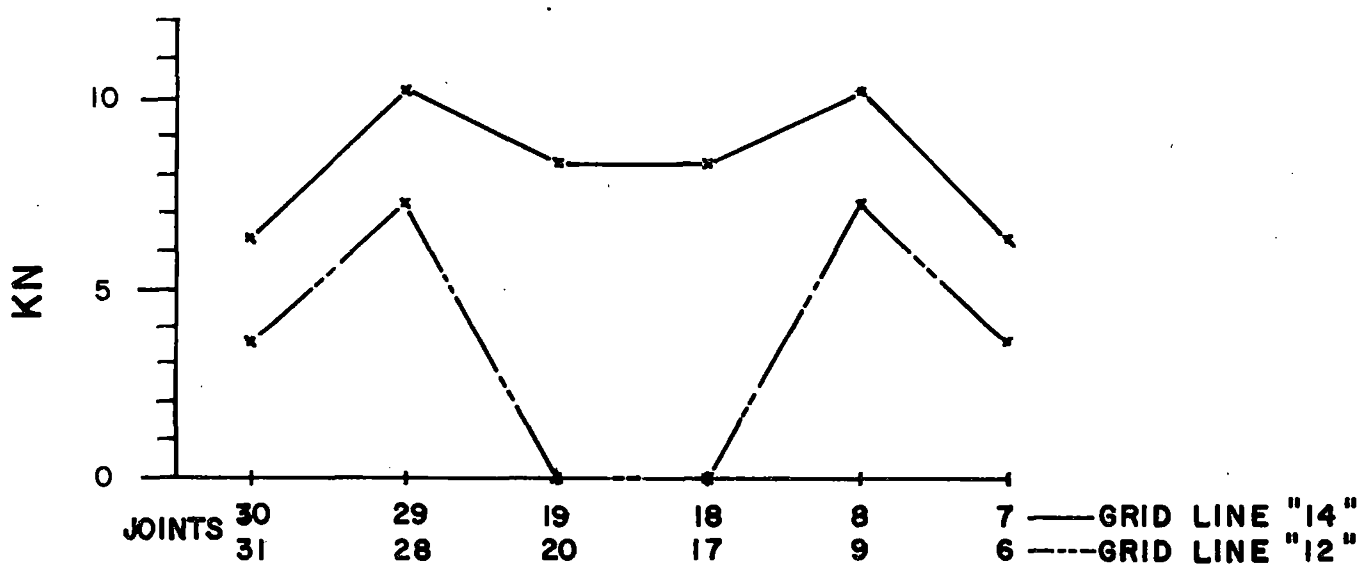
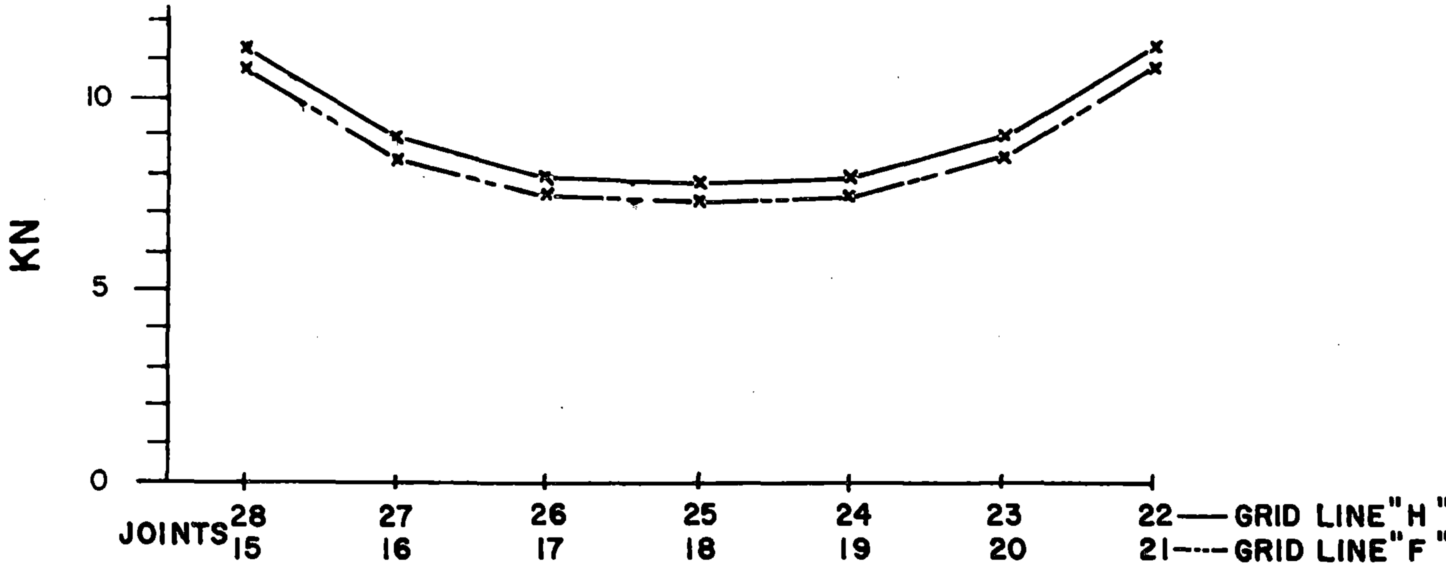


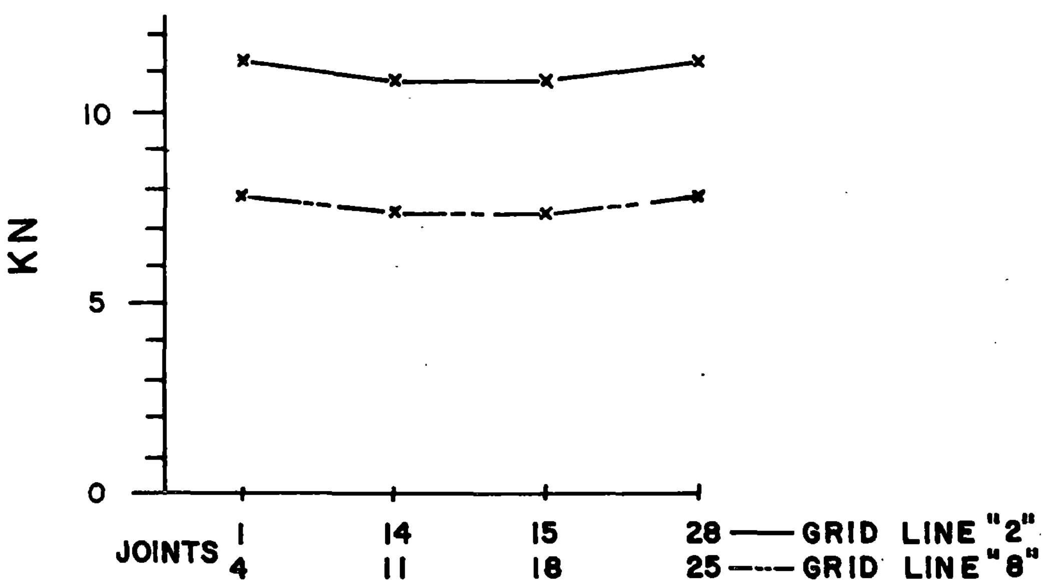
TRANSVERSE REACTIONS PROFILE

FRAME No. 2 - ACTUAL LOADING

SK-5.4



LONGITUDINAL REACTIONS PROFILE

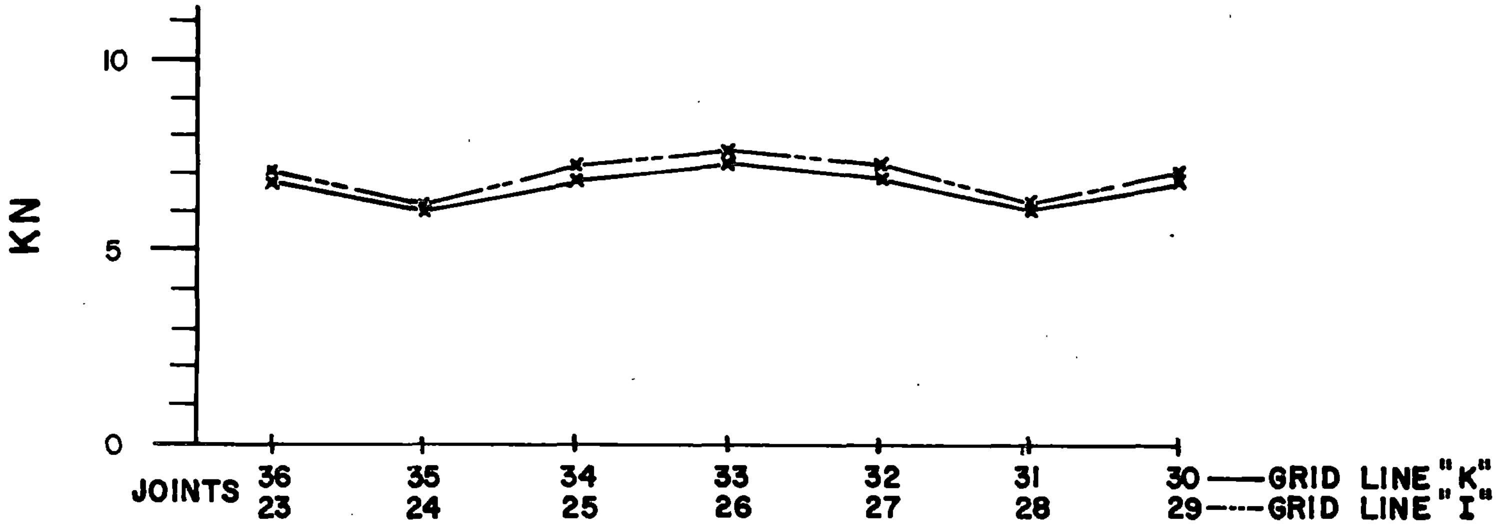


TRANSVERSE REACTIONS PROFILE

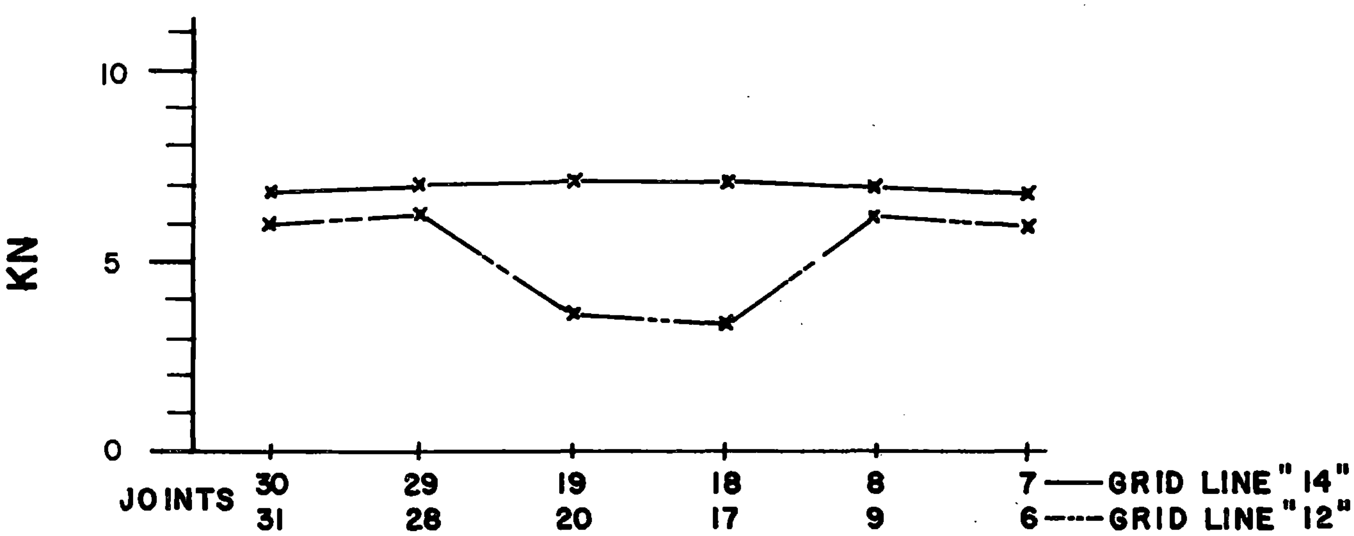
FRAME No. 1 - ACTUAL LOADING

(WITH ETHAFOAM PADS)

SK- 5.5



LONGITUDINAL REACTIONS PROFILE

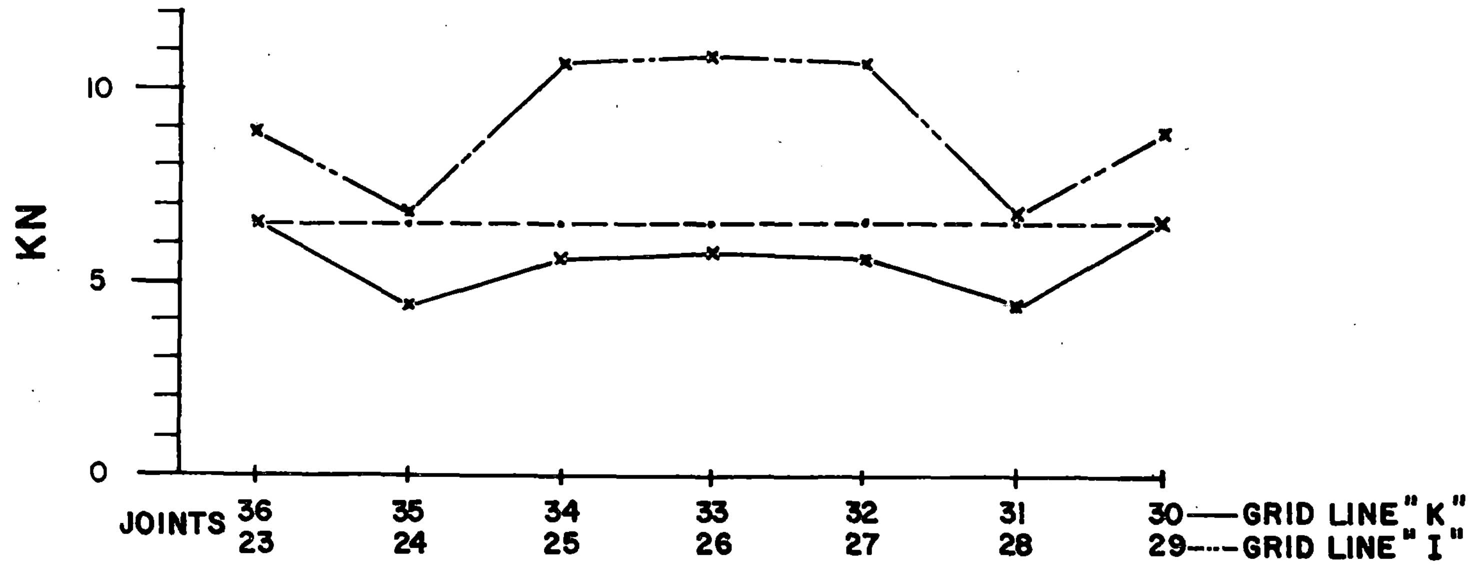


TRANSVERSE REACTIONS PROFILE

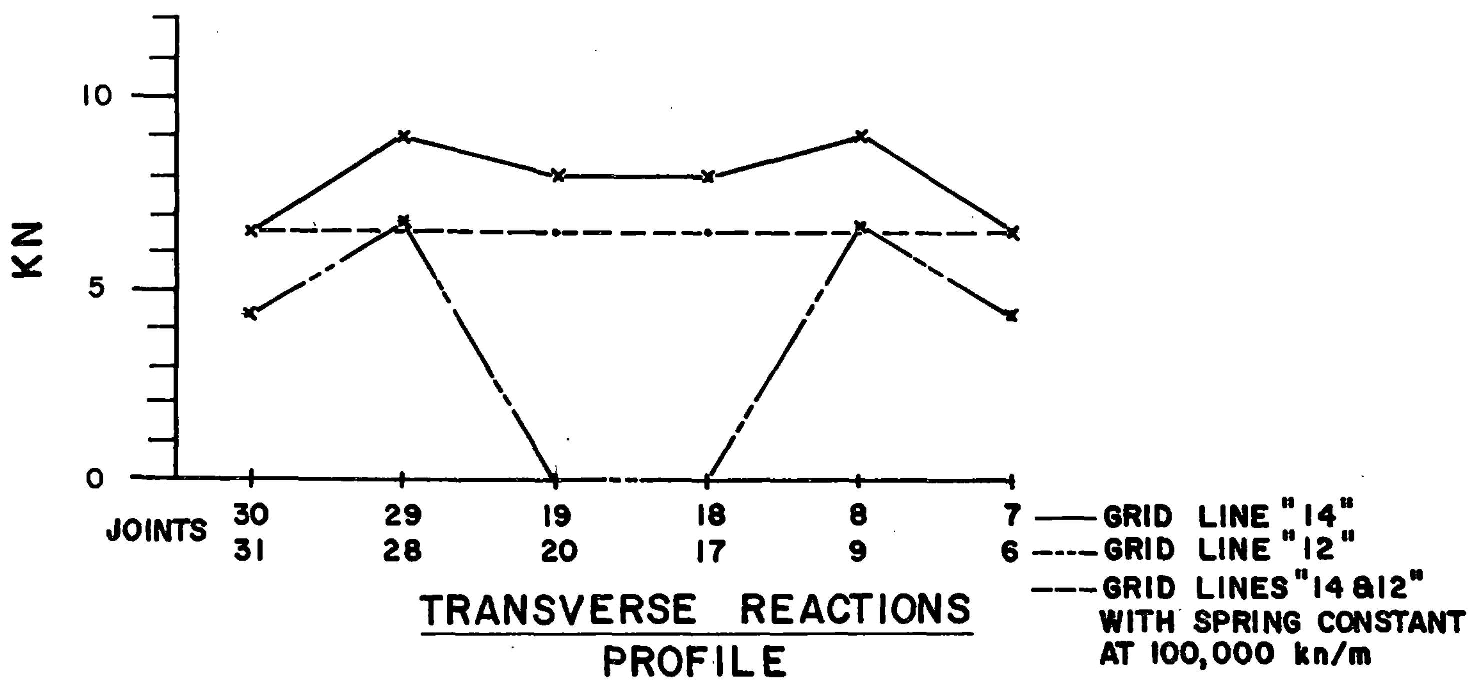
FRAME No. 2 - ACTUAL LOADING

SK-5.6

(WITH ETHAFOAM PADS &
SPRING CONSTANT AT 3471 kn/m)



LONGITUDINAL REACTIONS PROFILE

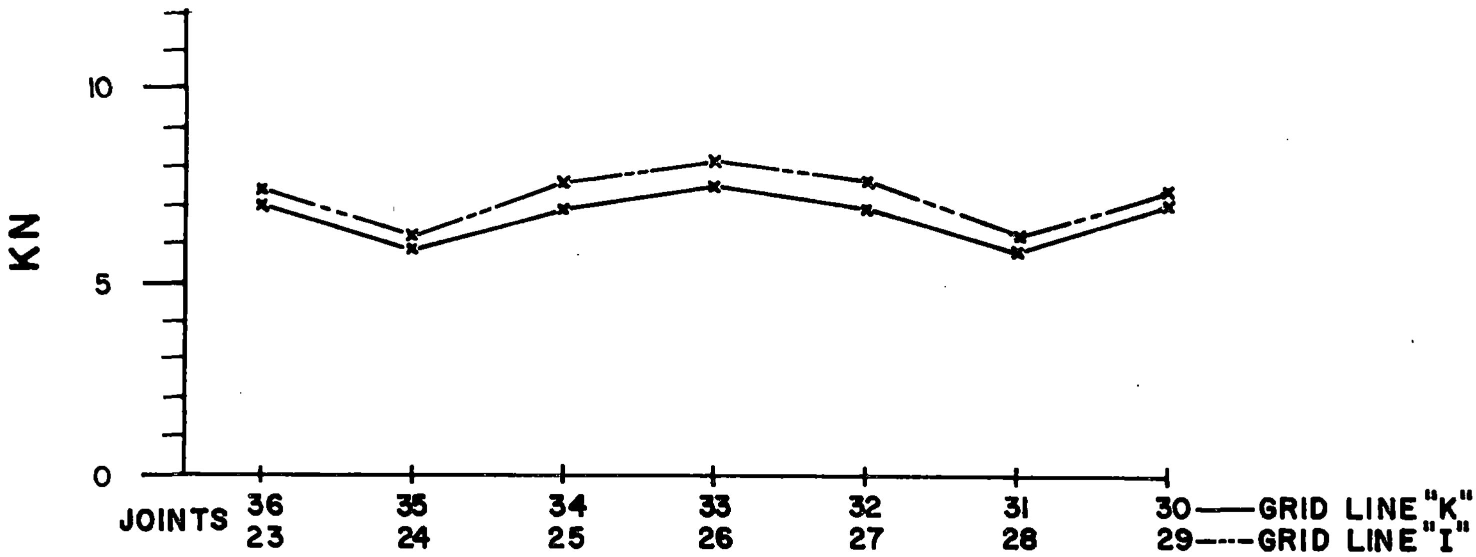


TRANSVERSE REACTIONS PROFILE

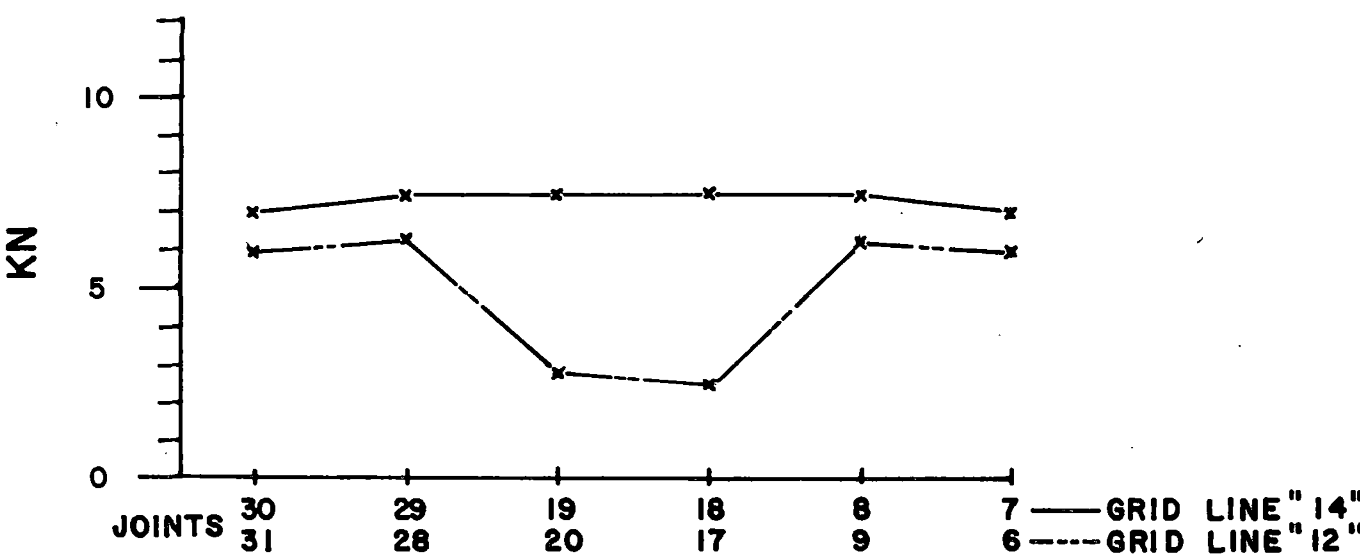
FRAME No. 2 - ACTUAL LOADING

(WITH SPRING CONSTANT AT 100,000 kn/m)

SK-5.7



LONGITUDINAL REACTIONS PROFILE



TRANSVERSE REACTIONS PROFILE

FRAME No. 2 - ACTUAL LOADING

(WITH SPRING CONSTANT AT 6000 kn/m)

SK-5.8

6.0 FUTURE FOUNDATION MONITORING

Objective: To optimize the frame member size and select the best footing configuration for the various possible seasonal support conditions.

Methodology: To have periodical measurement of deflection and loads at each support point over one full year with either the load cell or strain gauge method.

Instruments:

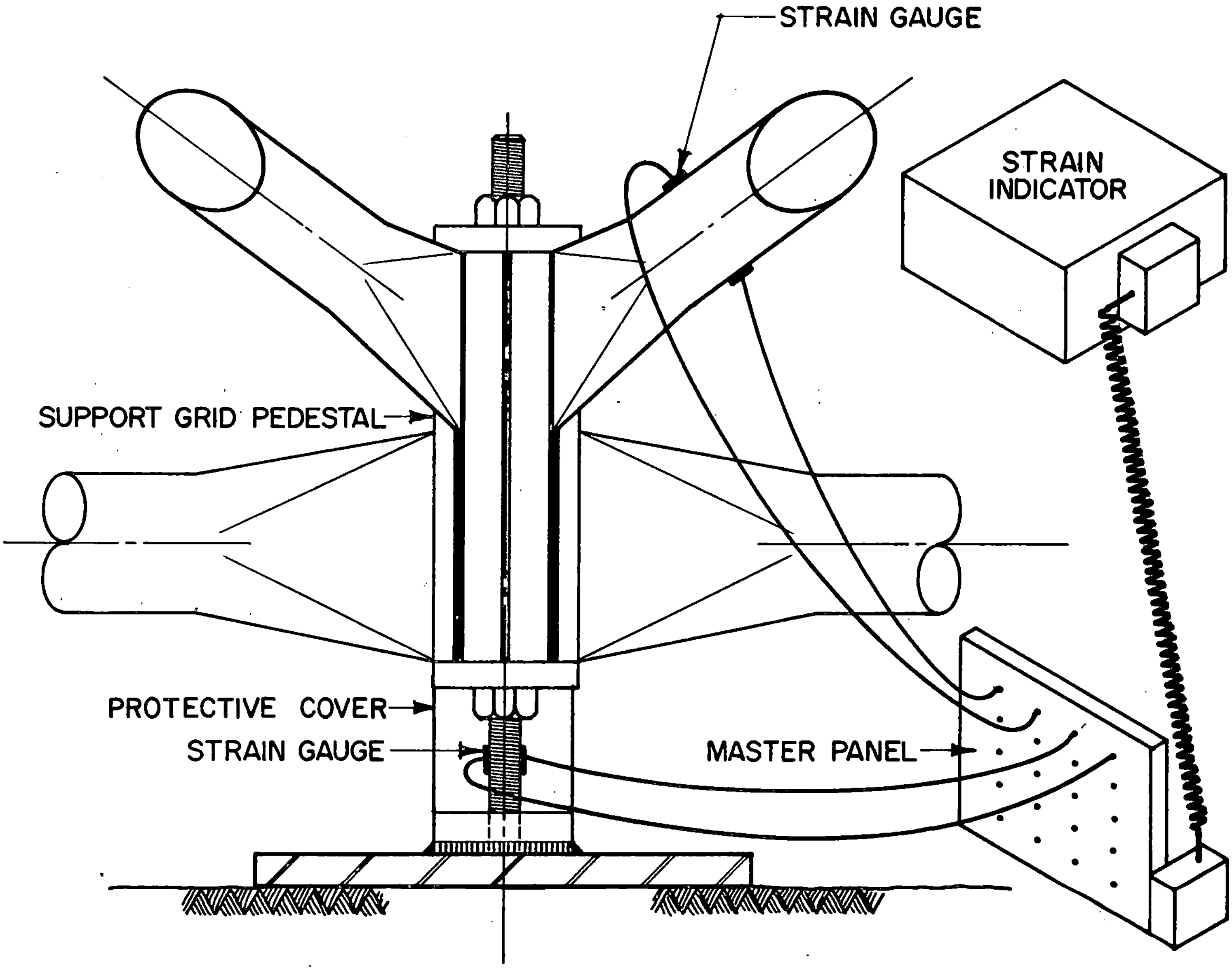
A) Strain Gauge Method (See Sketch SK-6.1)

- Adhesive resistance type or weldable vibrating wire type.
- Custom made system.
- Attach strain guages to support thread rods, tube members and hubs.
- Connect strain guages from each support point to a control panel situated at a convenient location so that data could be obtained with a strain indicator.
- With proper calibration with respect to temperature and wire length, load at each support point could then be deduced from the stress-strain relation of the support material.
- Estimated cost is $300/support.

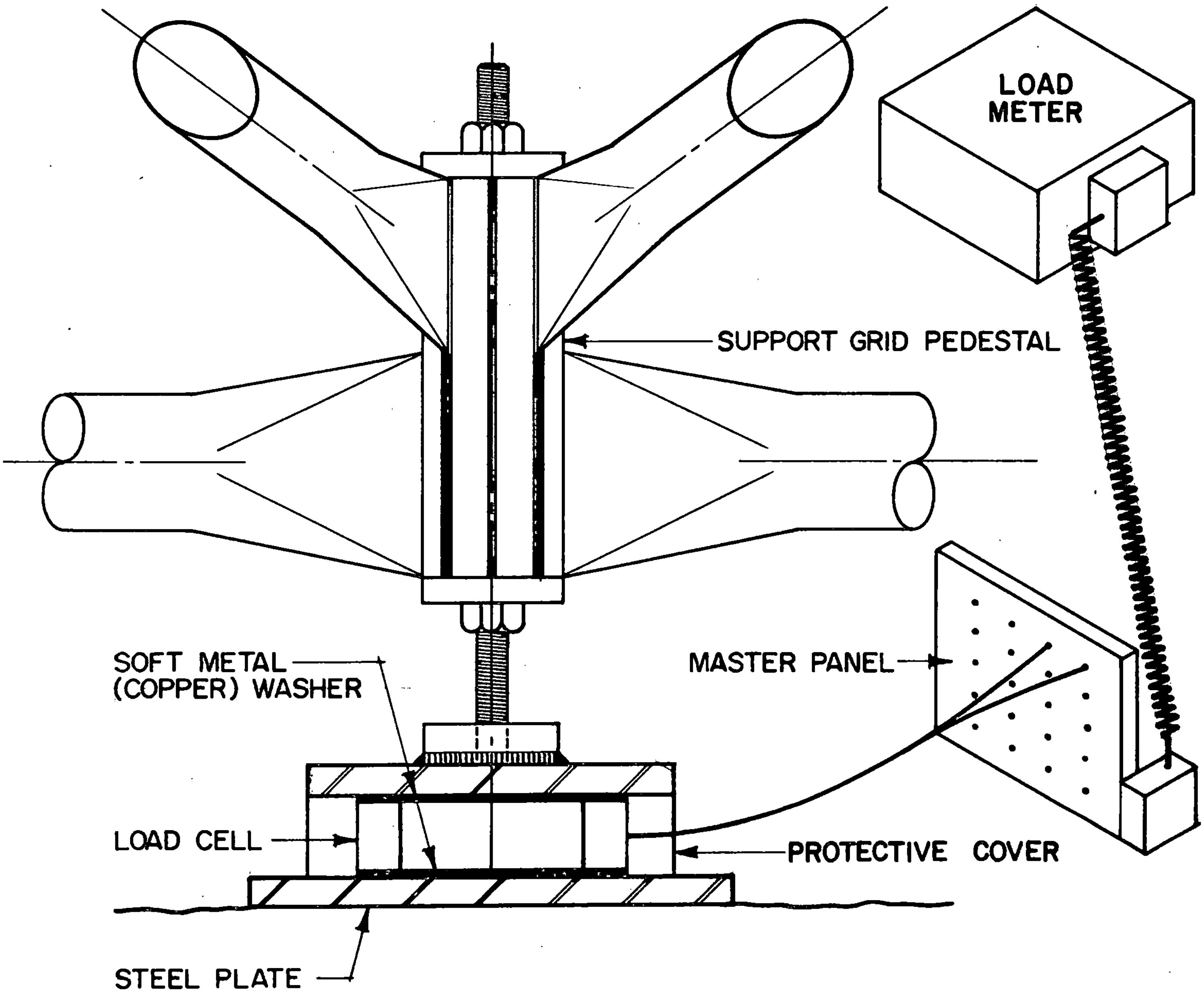
B) Load Cell Method (See Sketch SK-6.2)

- Manufactured off-the-shelf products such as "Strainsert" flat load cells, Transducers model 92, GLOTZL and KISTLER-MORSE load disc sensors.

- Direct load reading.
- Reusable.
- Estimated cost $1300/support.



STRAIN GAUGE METHOD



LOAD CELL METHOD

7.0 CONCLUSIONS

Multipoint supported metal space frame is a viable alternative to the conventional foundation system. The frame is relatively light and easy to erect as demonstrated by the Hay River space frame being completed in three days by three unskilled labourers under the direction of the manufacturer's representative..

At Hay River, besides providing a level working surface and covering a septic tank, the sand pad used was not essential as part of the foundation system. The sand pad cannot prevent the ultimate thawing of the permafrost due to heat flow into the ground from the building. Since minimum site preparation and geotechnical input are a requirement, the space frame system is more economical than the pile and deep spread footing foundation. Although the initial capital cost is more than the surface footing system, the space frame's ability to bridge over some soft spots or relieve the frost heave pressure, should allow for minimal relevelling requirements and relative low long term maintenance and repair costs.

From the field monitoring results, the space frame in Hay River has moved upward quite evenly during the winter season with a maximum vertical displacement of 29 mm and moved back down after the spring thaw with a maximum settlement of 37 mm. The house structure appears to be in good condition without any sign of racking or cracking. There were no visible damage to the space frame tubes or hubs. Since steel and aluminum alloy are quite inert to the air pollutant attacks, the frame should have a long life cycle if the differential settlement can be limited to a minimum.

The computer analysis revealed that actual loadings must be used in the analysis because the worst case will have the combination of minimum superimposed live loads and poor soil conditions due to spring thaw. Also, certain frame members were found to be oversized but not rigid enough to redistribute the loads. As most of the loads was transferred to the building outside walls, the soil under the footings along the perimeter were overstressed. The field measurement confirmed that the perimeter footings settled more than the interior footings. Theoretically, by modifying the frame with extra perimeter footings and the addition of 400 mm x 400 mm x 100 mm thick polyethylene foam pad, the loads are able to be redistributed to the interior footings with bearing stresses near the estimated allowable limit of 50 Kpa (1015 psf).

The Native soils could behave as a spring only if it is a thick layer of uniform granular material and uniform moisture content.

Using a multi-point supported metal space frame to reinforce an existing foundation in Fort Franklin was quite successful because the house structure had a fairly rigid floor framing. Load redistribution in this metal frame footings and glu-lam beam composite structure is more complicated than the independent space frame foundations. Further monitoring and analysis is necessary to assess its behaviour and potential. If possible, glu-lam beam will be replaced by less expensive but more rigid prefabricated wall panels.

The semi-rigid connection between the tubes and the hubs has contributed to part of the frame stiffness. The understanding of its effects on the frame requires indepth analysis and experiments which is out of the scope of this work.

Further study of the space frame in a controlled environment with strain gauge monitoring is necessary to optimize the superstructure framing, the space frame's configuration and member size, and the footing type that will be adaptable to different climate and soil conditions other than Arctic region such as swamps in tropical area.

8.0 RECOMMENDATIONS

Future house framing should be modified such that at least half of the load will occur to the centre of the space frame foundation. This can be achieved by having a central load bearing wall. If the loads and elevations at each footing are more or less the same initially, the space frame will only have to redistribute the loads resulting from the ground movements.

A 400 mm x 400 mm x 100 mm thick polyethylene foam pad would be the most optimum footing for the modified frame (No. 2) configuration and loadings. Further computer simulation and analysis are required to determine the pad size if different frame configuration and/or house structure such as a 2 storey type is to be used.

Strain gauges are the preferred and the recommended instrumentation to be used for the monitoring because of its economy and versatility. Frame member and footing size could be optimized by utilizing data obtained from periodical measurement of the loads and deflections.

A full scale frame module experiment in a controlled environment would be advantageous as it may identify the type of frame and footing combination that will suit various climate and soil conditions other than those in the Arctic.

Future space frame designs should have the following basic specification:

Materials	- either galvanized steel or aluminum alloy.
Connectors	- simple mechanical devices connecting the frame members and the frame to the house structure.

Footings	- 400 x 400 steel plate with threaded rod or bolts for level adjustment.
	- variation of footing loads shall not be more than 10%.
	- maximum reaction = 8 Kn (unfactored)
Design Criteria	- members shall be able to withstand the loads without any overstressing and relative settlements of span/360.
	- National Building Code requirements.

A P P E N D I C E S

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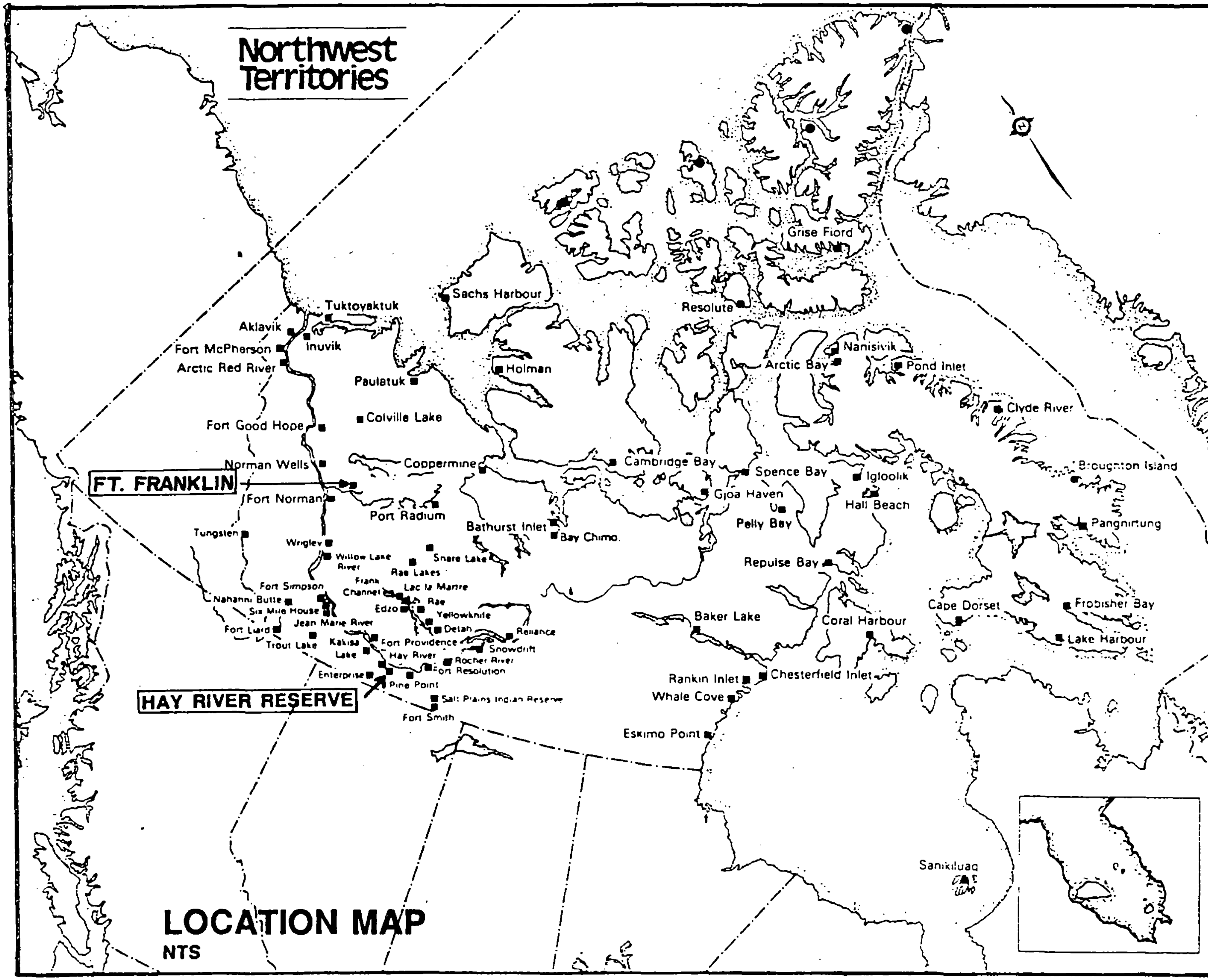
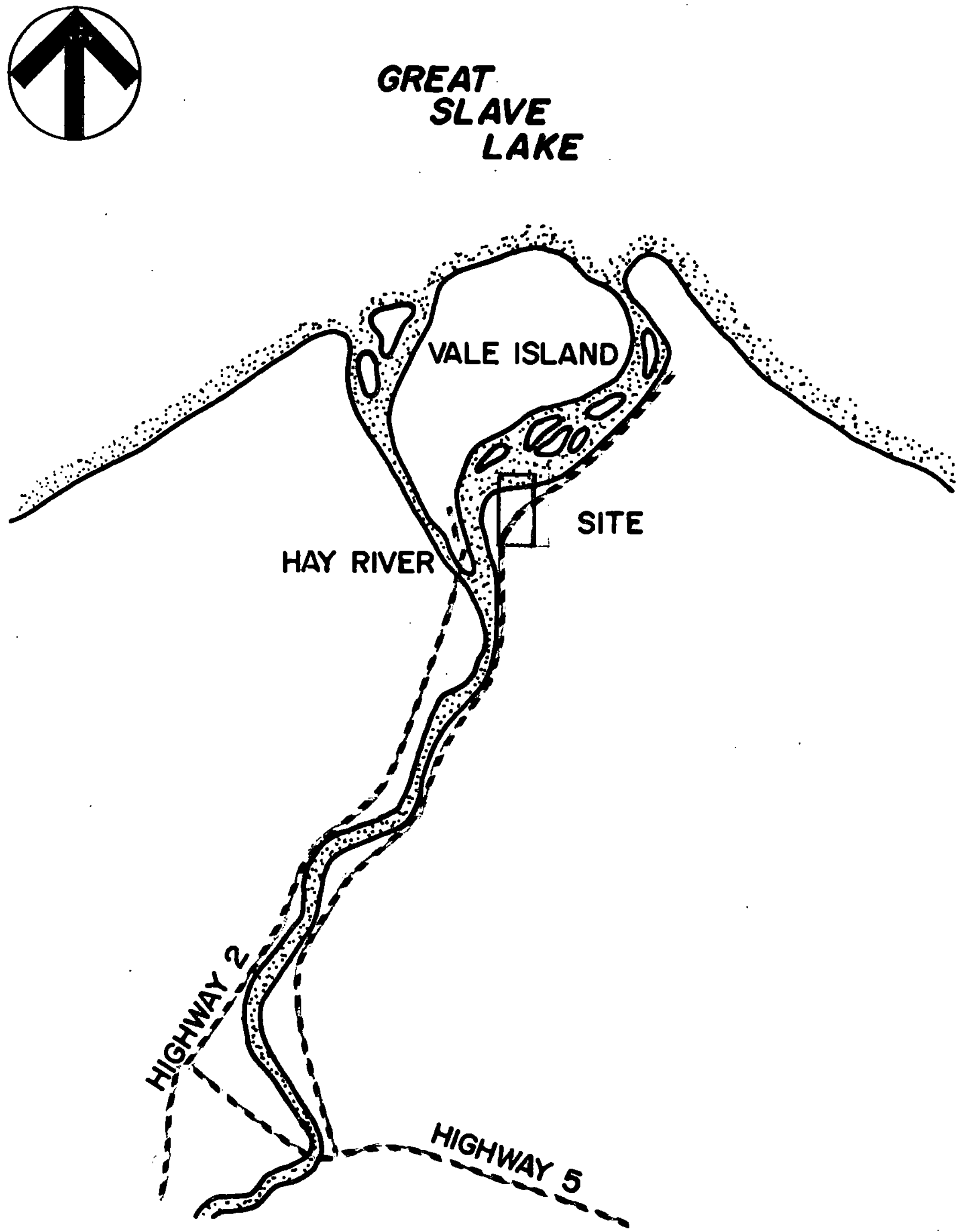
A P P E N D I X   A

Site Plans



Northwest Territories
Grise Fiord
Sachs Harbour
Resolute
Tuktoyaktuk
Aklavik
Inuvik
Fort McPherson
Arctic Red River
Paulatuk
Holman
Nanisivik
Arctic Bay
Pond Inlet
Clyde River
Fort Good Hope
Colville Lake
Norman Wells
Coppermine
Cambridge Bay
Spence Bay
Igloolik
Broughton Island
FT. FRANKLIN
Fort Norman
Port Radium
Gjoa Haven
Hall Beach
Pelly Bay
Bathurst Inlet
Bay Chimo
Pangnirtung
Tungsten
Wrigley
Willow Lake River
Snare Lake
Rae Lakes
Repulse Bay
Fort Simpson
Frank Channel
Lac la Martre
Nahanni Butte
Six Mile House
Edzo
Rae
Yellowknife
Baker Lake
Coral Harbour
Cape Dorset
Frobisher Bay
Jean Marie River
Fort Liard
Detah
Reliance
Trout Lake
Kakisa Lake
Fort Providence
Snowdrift
Lake Harbour
Hay River
Rocher River
Fort Resolution
Enterprise
Pine Point
Rankin Inlet
Chesterfield Inlet
HAY RIVER RESERVE
Whale Cove
Salt Plains Indian Reserve
Fort Smith
Eskimo Point
Sanikiluaq
LOCATION MAP
NTS



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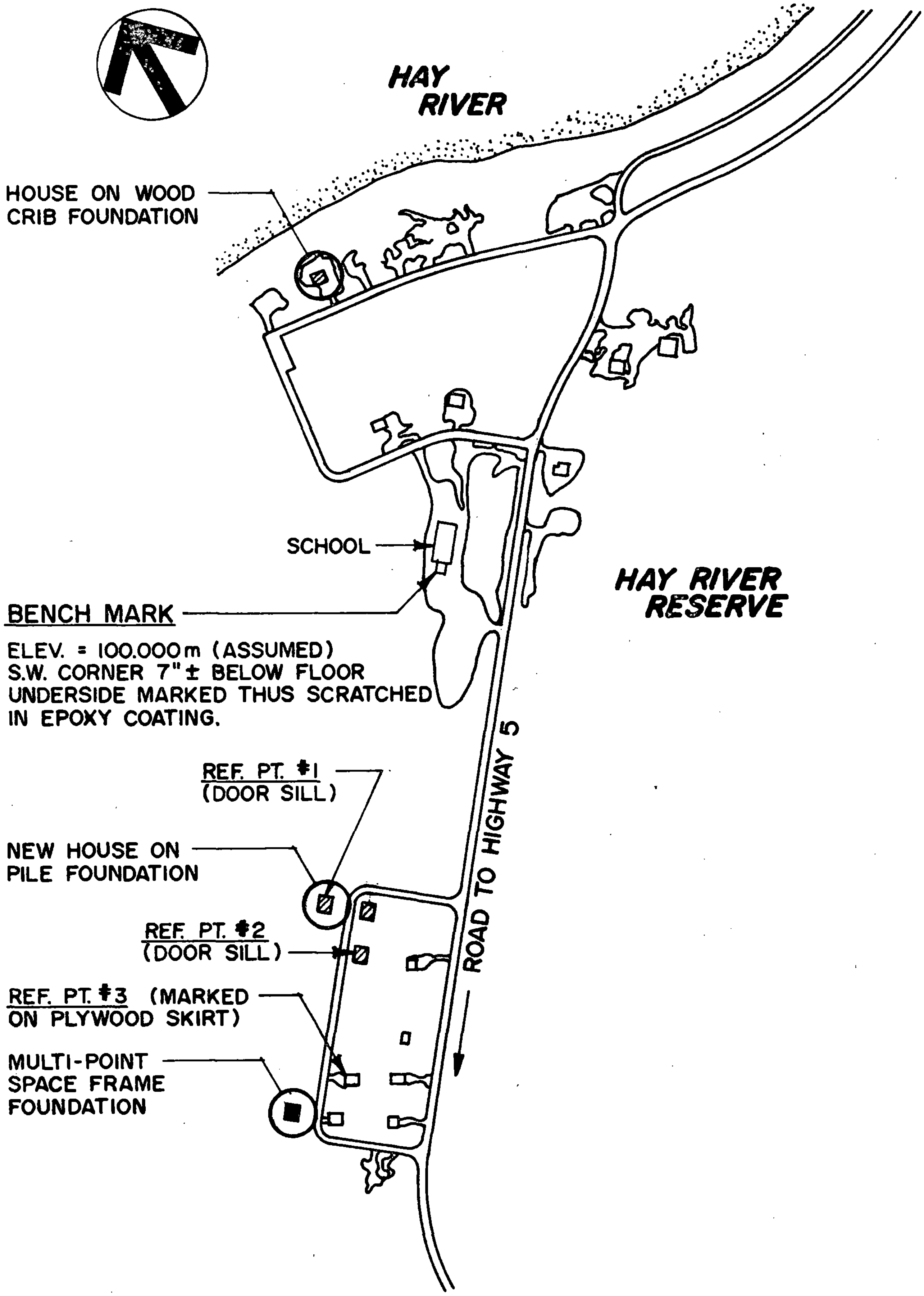

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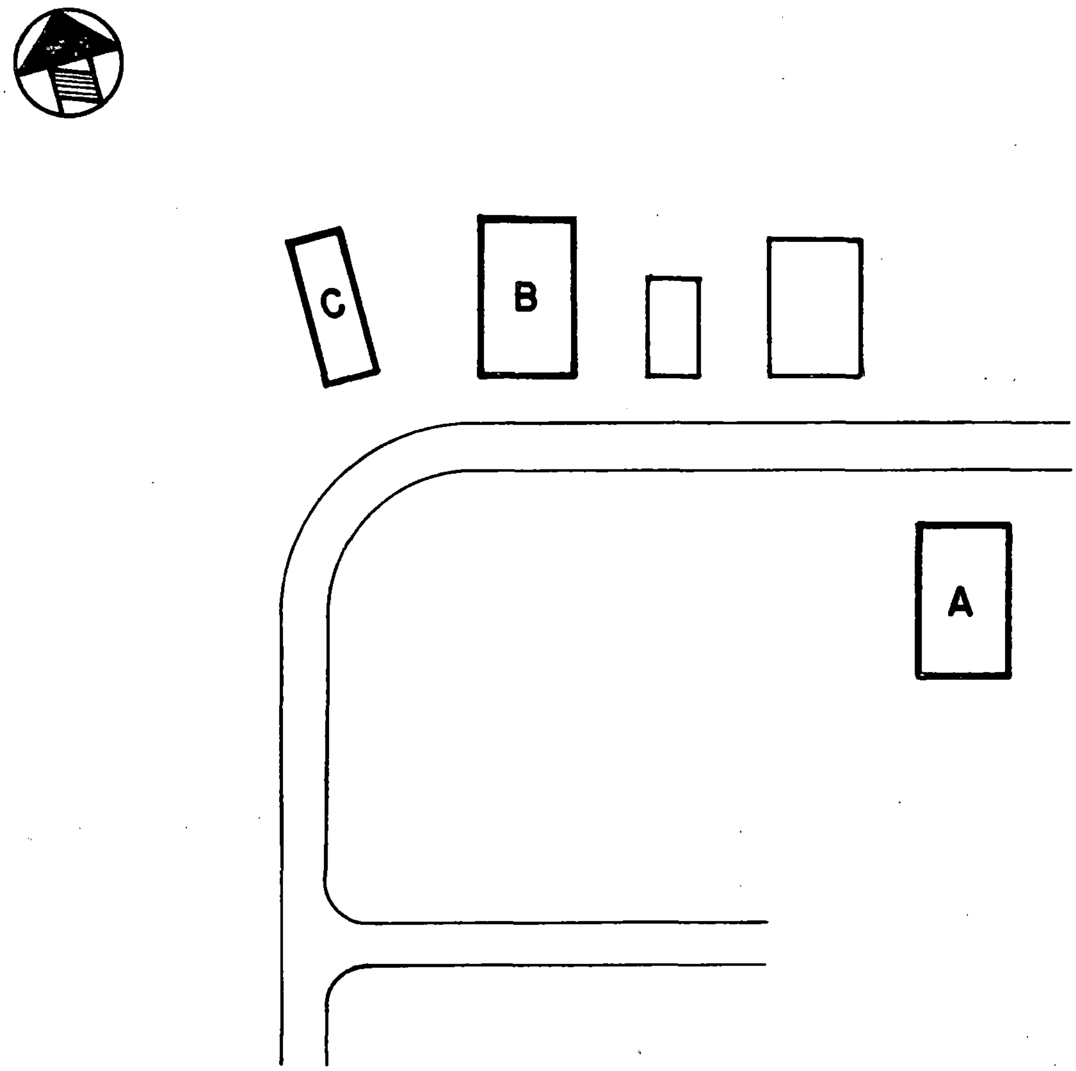
CMHC FOUNDATIONS- FORT FRANKLIN



3 BUILDINGS SET ON SPACE FRAME *AFTER CONSTRUCTION.*

APPENDIX B

COMPUTER MODELS FOR
HAY RIVER SPACE FRAME

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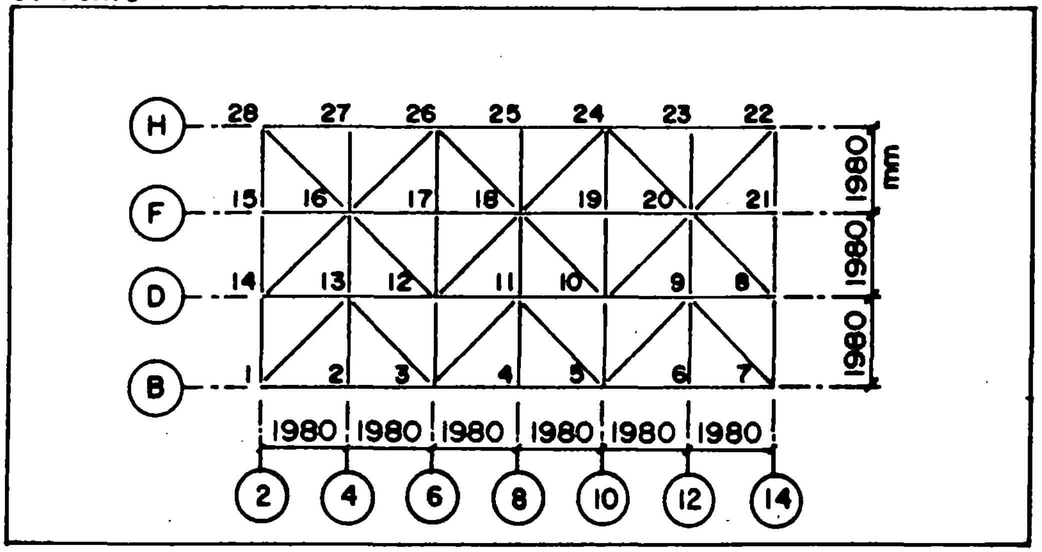
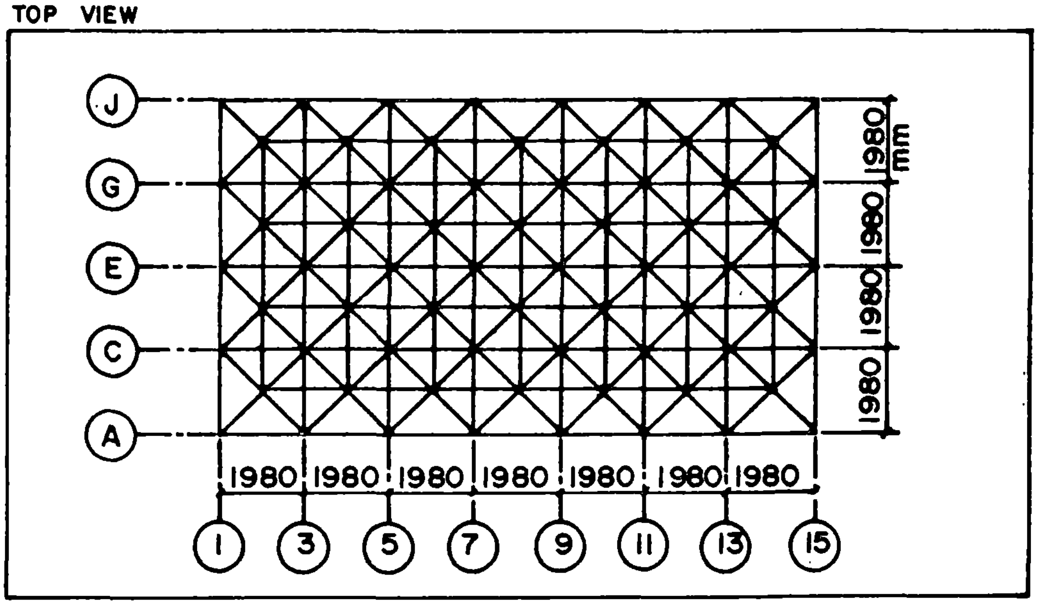
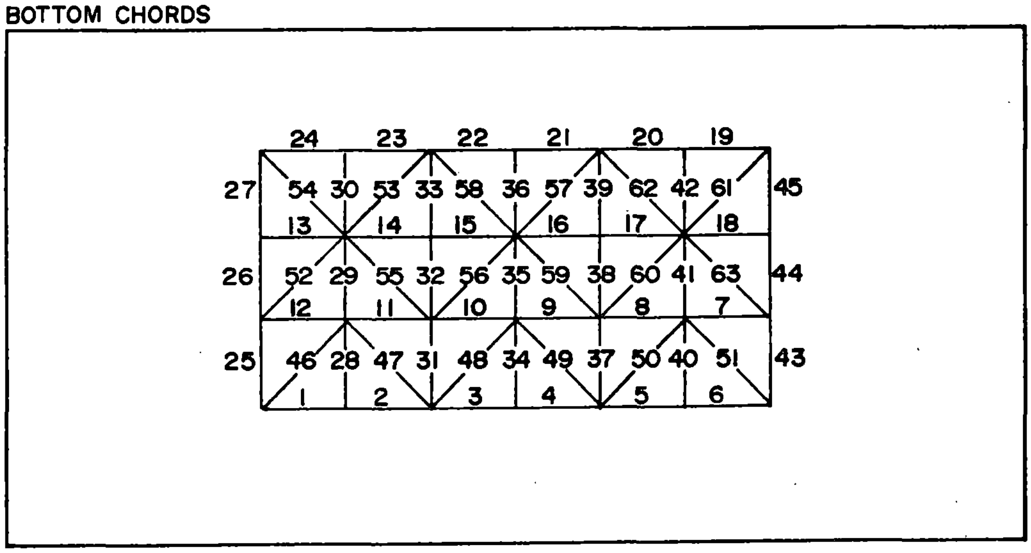
SUPPORTS



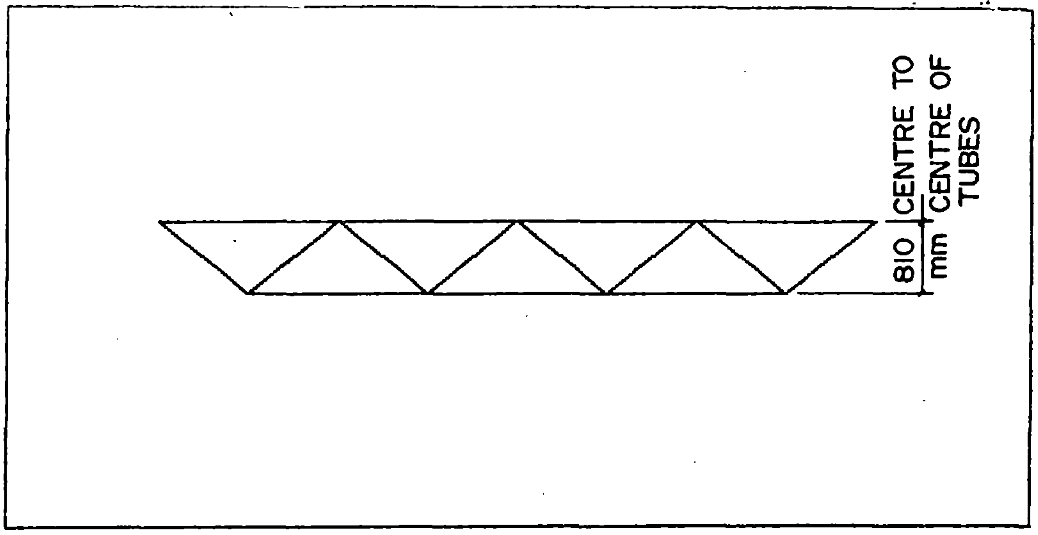
TOP VIEW



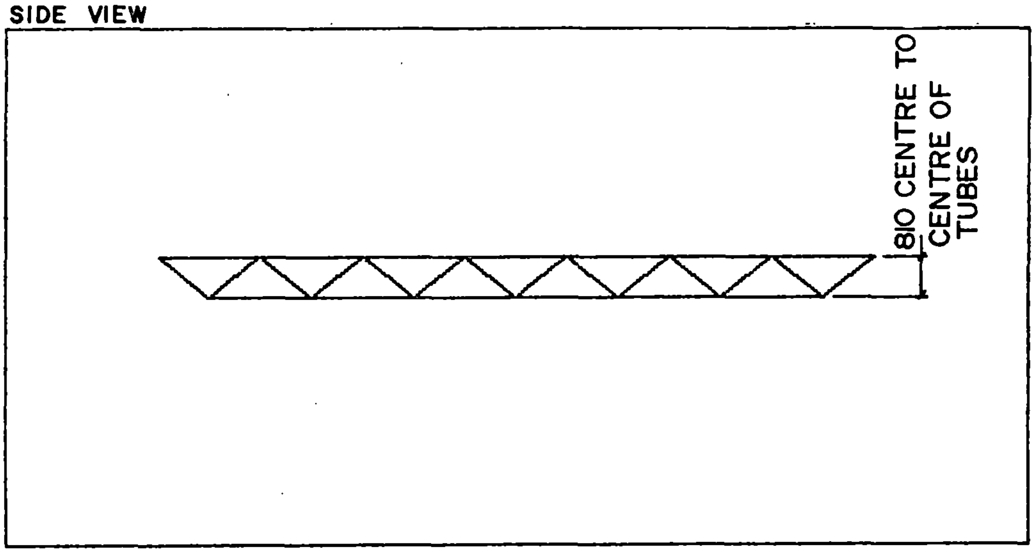
BOTTOM CHORDS



END VIEW



SIDE VIEW



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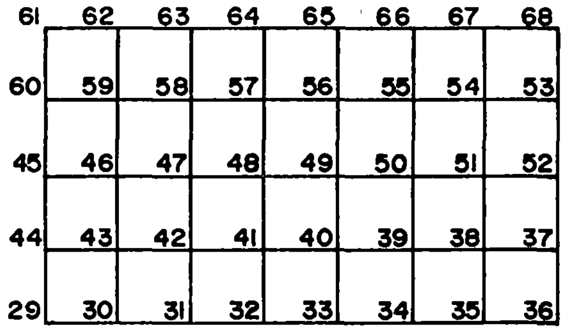
TOP JOINTS



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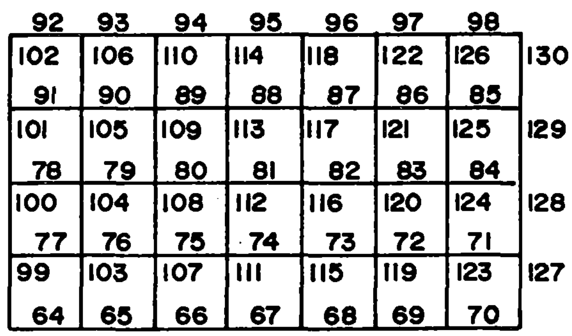

A P P E N D I X   C

FIELD DATA - HAY RIVER

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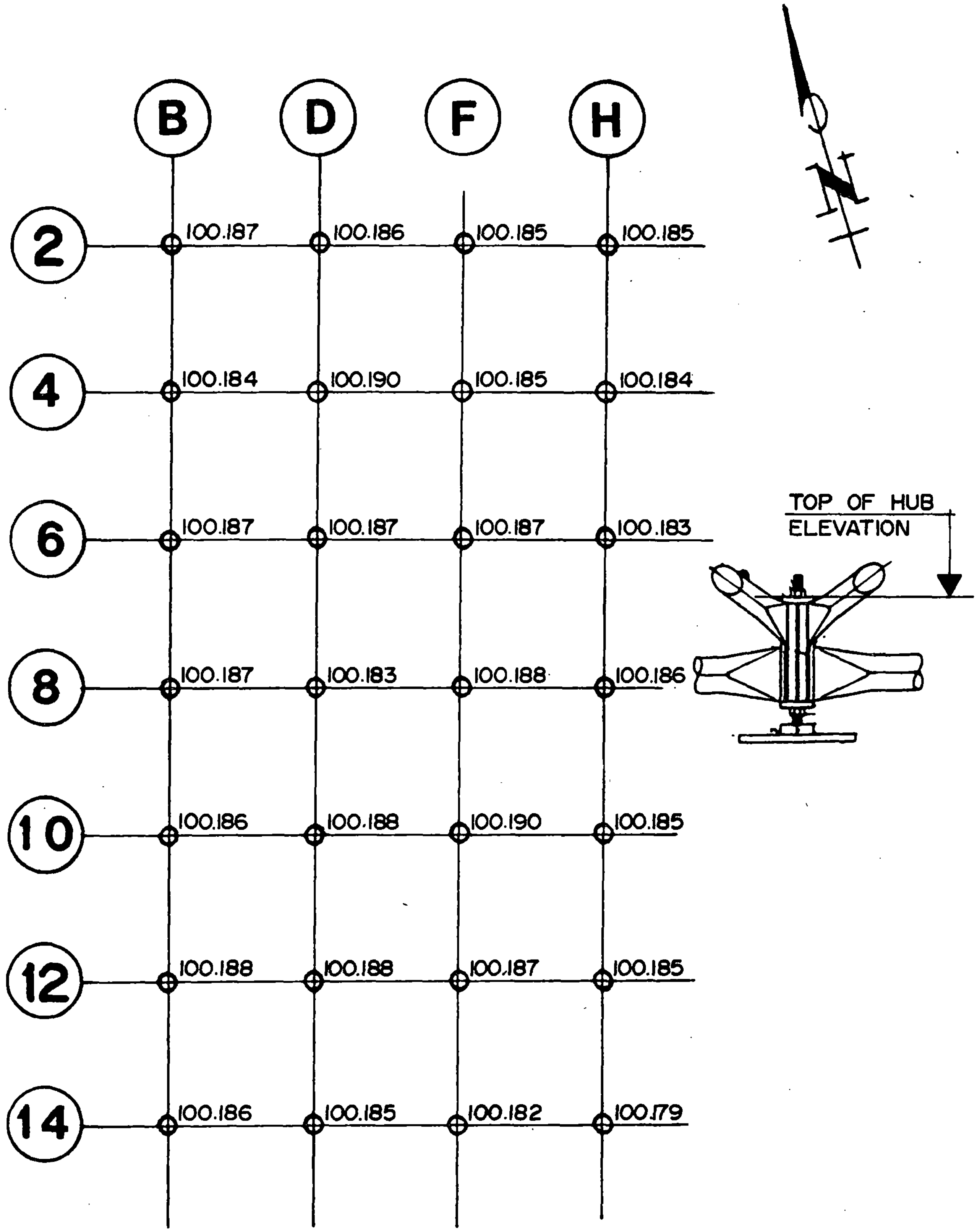

TOP OF HUB ELEVATIONS (M)

OCTOBER 7, 1987

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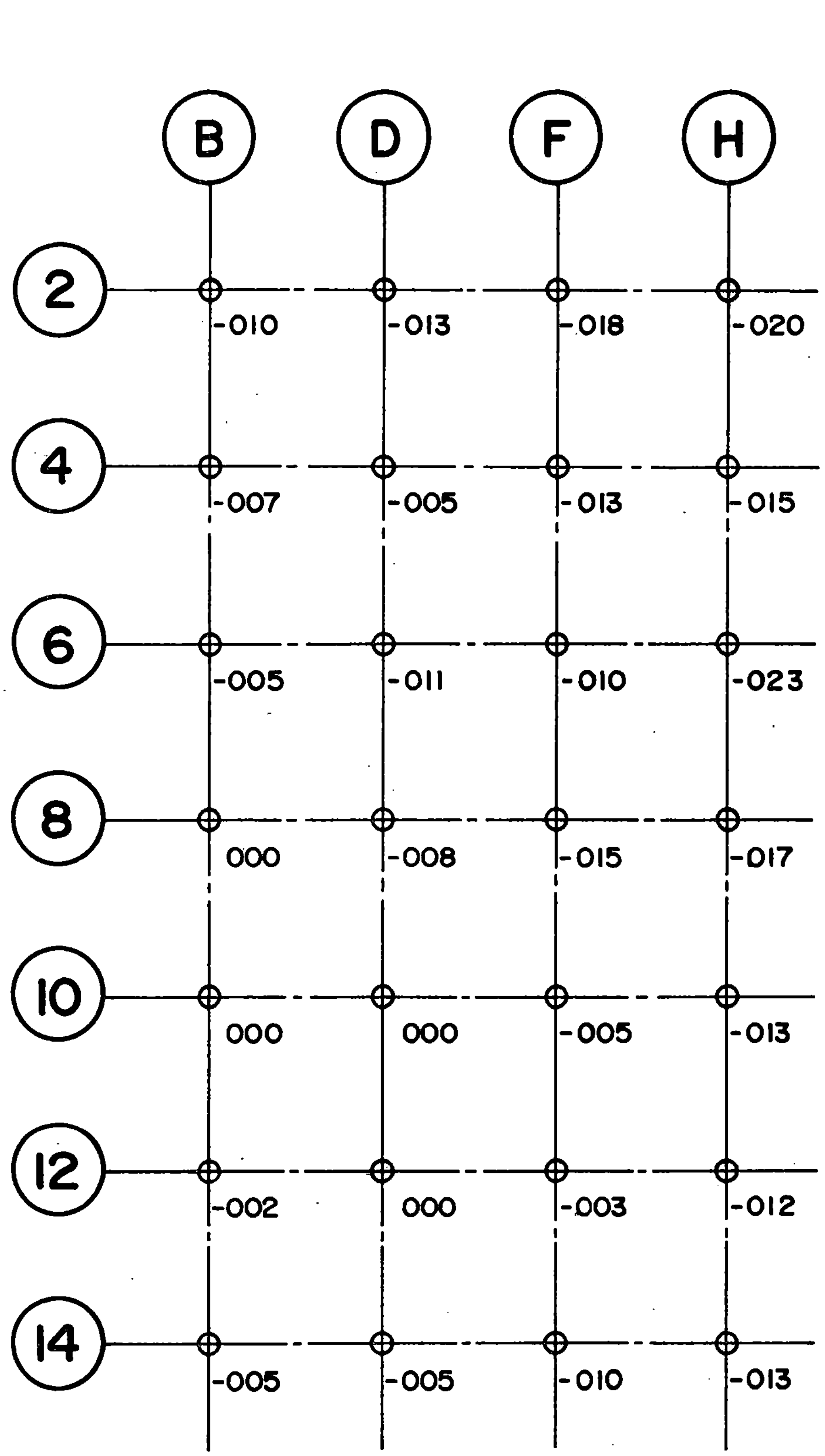
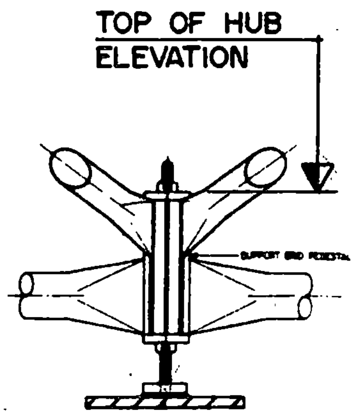


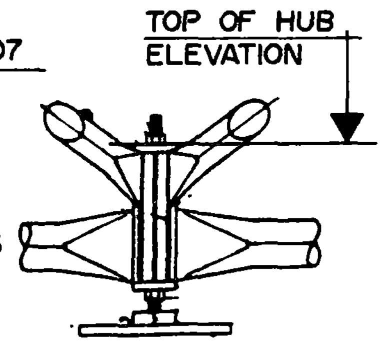


RELATIVE ELEVATION (mm)

DECEMBER 9, 1987

Reid
Crowther

	B	D	F	H
2	100.191	100.194	100.192	100.188
4	100.202	100.209	100.205	100.199
6	100.201	100.211	100.213	100.207
8	100.208	100.212	100.215	100.213
10	100.206	100.216	100.222	100.219
12	100.207	100.214	100.218	100.217
14	100.203	100.206	100.207	100.209



TOP OF HUB ELEVATIONS (M)

MARCH 30, 1988

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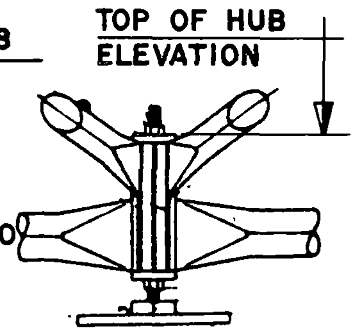
	B	D	F	H
2	100.187	100.190	100.190	100.189
4	100.190	100.200	100.198	100.195
6	100.187	100.200	100.200	100.198
8	100.190	100.196	100.197	100.200
10	100.181	100.190	100.198	100.195
12	100.176	100.183	100.187	100.190
14	100.166	100.172	100.171	100.173



TOP OF HUB ELEVATIONS (M)

JULY 06, 1988

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The resurvey of nearby homes on pile foundations has the following changes in elevations:

	ELEVATIONS (m)		
Ref. # Pt.*	September 1987	March 1988	July 1988
1	100.424	100.437	100.430
2	100.596	100.587	100.591
3	101.390	101.423	101.403

* See site plan in Appendix A.

APPENDIX D

FIELD DATA - FORT FRANKLIN

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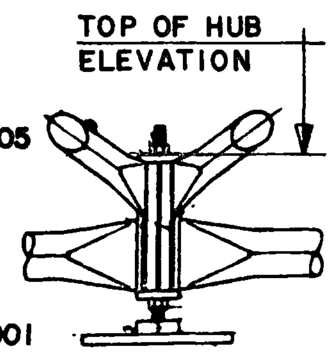
CMHC FOUNDATIONS- FORT FRANKLIN

BUILDING 'A' 4- PLEX

— STREET —

99.999	100.000	100.003	100.002
100.000	99.999	100.004	100.005
100.001	100.001	100.003	100.005
100.002	100.005	100.004	100.005
100.005	100.005	100.005	100.001
100.000	100.003	100.006	100.005
99.999	100.002	100.004	100.006
100.000	100.000	100.002	100.000

N



TOP OF HUB ELEVATIONS (M)

JULY 07, 1988

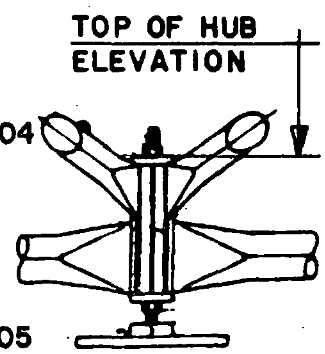
Reid Crowther

CMHC FOUNDATIONS - FORT FRANKLIN

BUILDING 'B' 4-PLEX

100.001	100.000	99.997	100.002
100.001	99.999	99.997	100.003
100.003	100.001	99.997	100.003
100.004	100.001	99.999	100.004
100.004	100.002	100.000	100.005
100.003	100.000	99.999	100.005
100.001	99.999	99.998	100.003
100.000	99.998	99.998	100.002

—STREET—



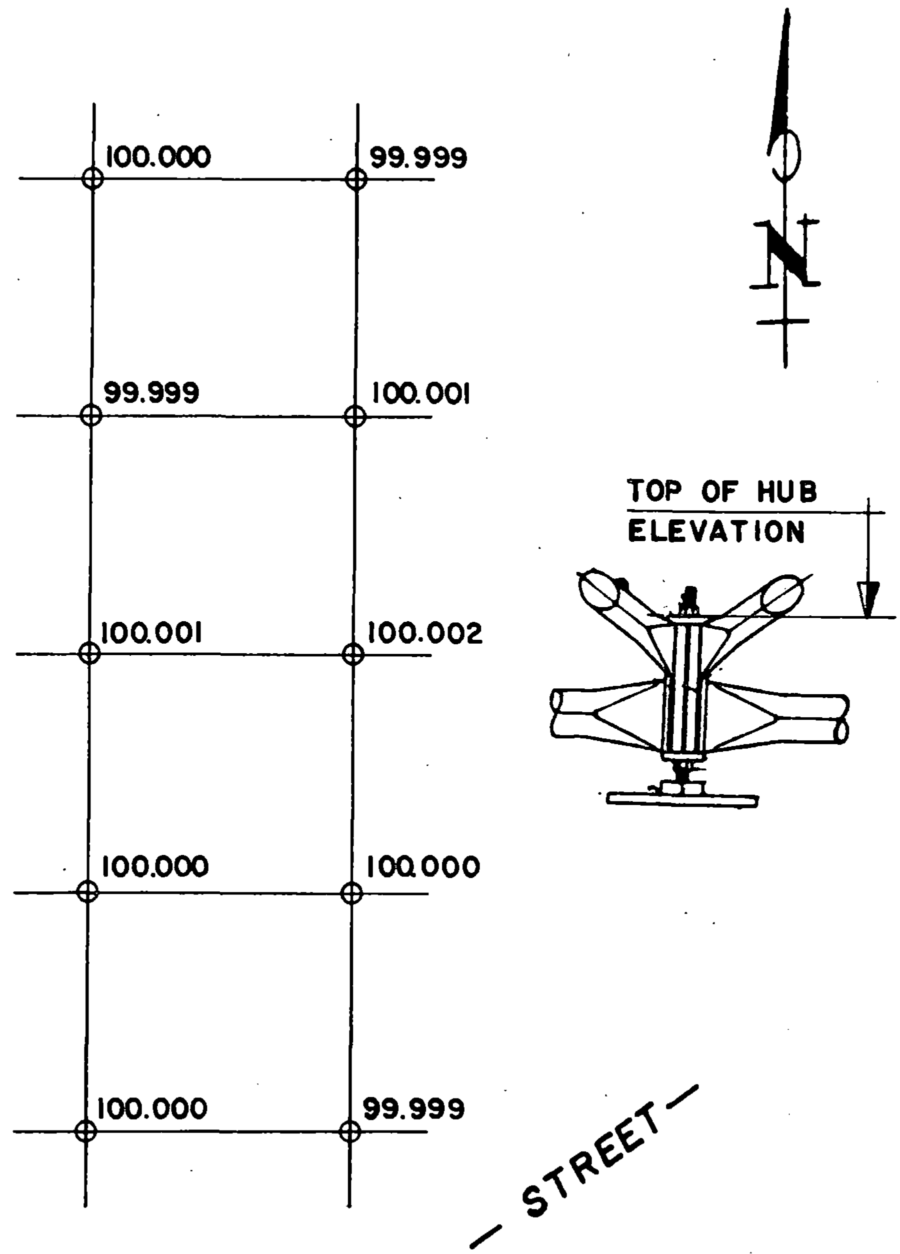
TOP OF HUB ELEVATIONS (M)

JULY 07, 1988

Reid Crowther

CMHC FOUNDATIONS - FORT FRANKLIN

DUPLEX 'C'



TOP OF HUB ELEVATIONS (M)

JULY 07, 1988

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A P P E N D I X   E

PHOTOGRAPHS - HAY RIVER

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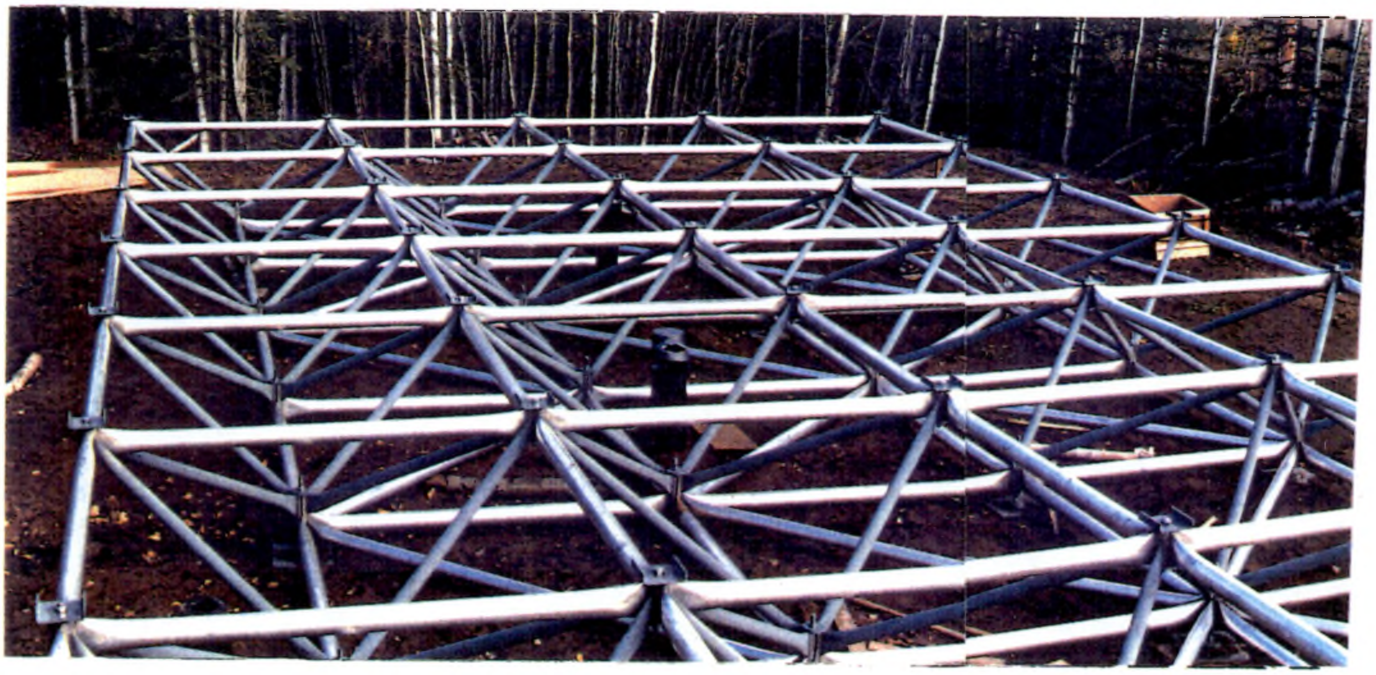


1

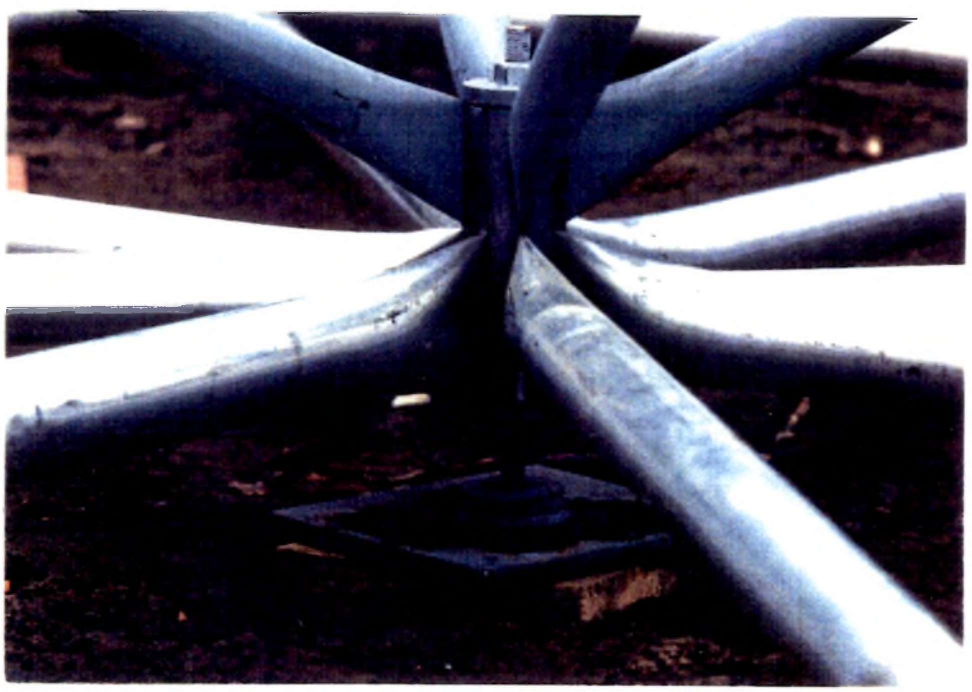
SPACE FRAME - TOP VIEW

2

SPACE FRAME - SIDE VIEW

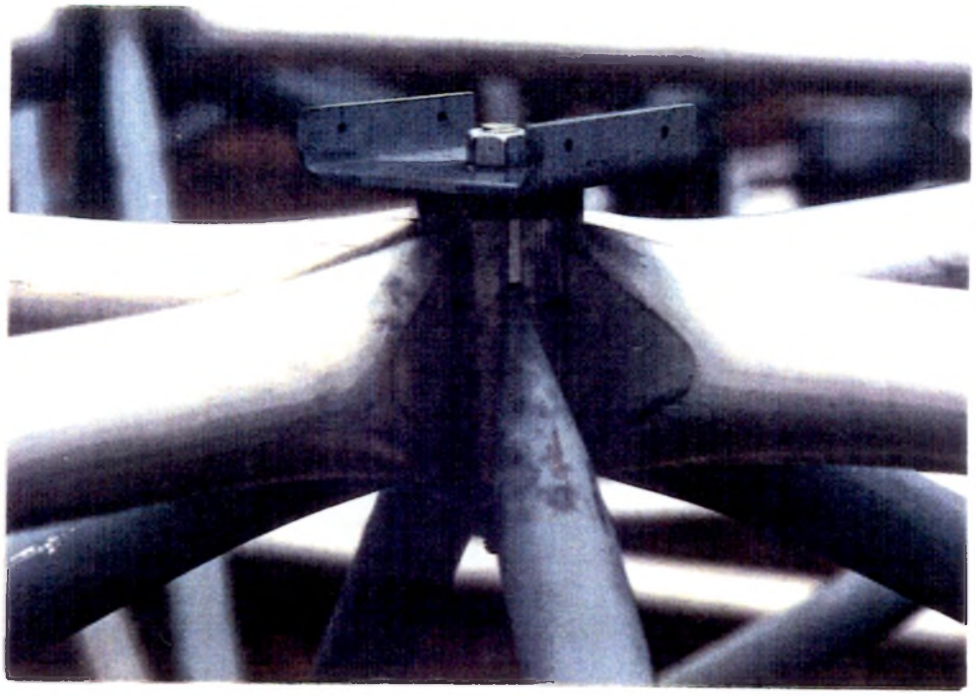
EXTERIOR
FOOTING

3



INTERIOR
FOOTING

4



5

TOP BRACKET

6

TYPICAL MEMBER END PLUG

SPACE FRAME
ON LEVELLING
TIMBER

7

BUILT-UP
SAND PAD

8

PRE-FABRICATED
WALL PANELS

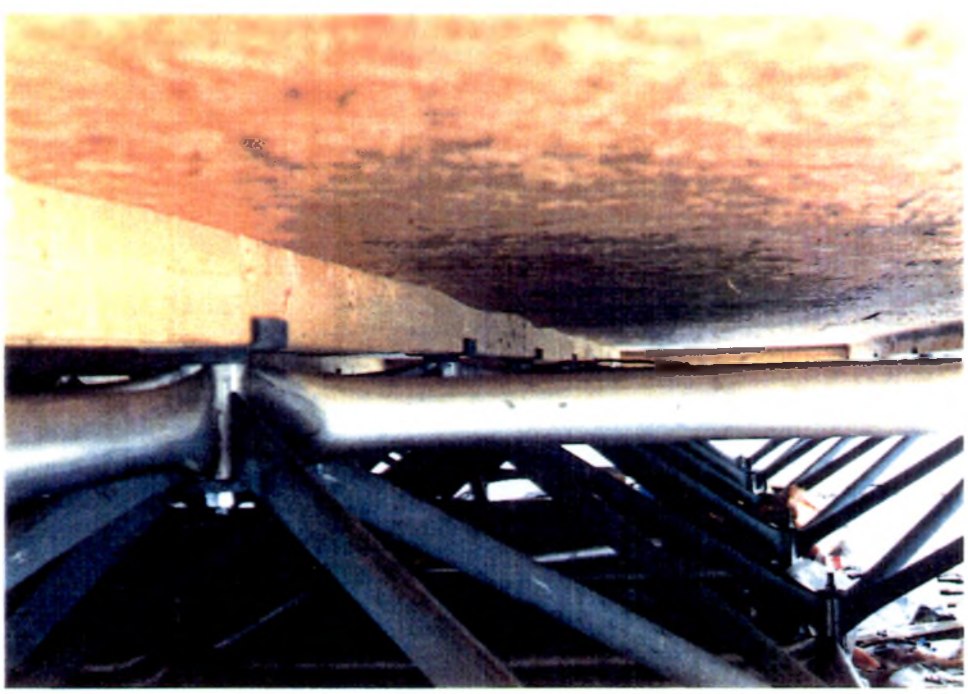
9

SEWAGE PIPE TO
SEPTIC TANK

10

11

FINISHED HOUSE ON SPACE FRAME



HOUSE FRAME
38 x 140 (2 x 6)
WOOD BEAM
ON BRACKET

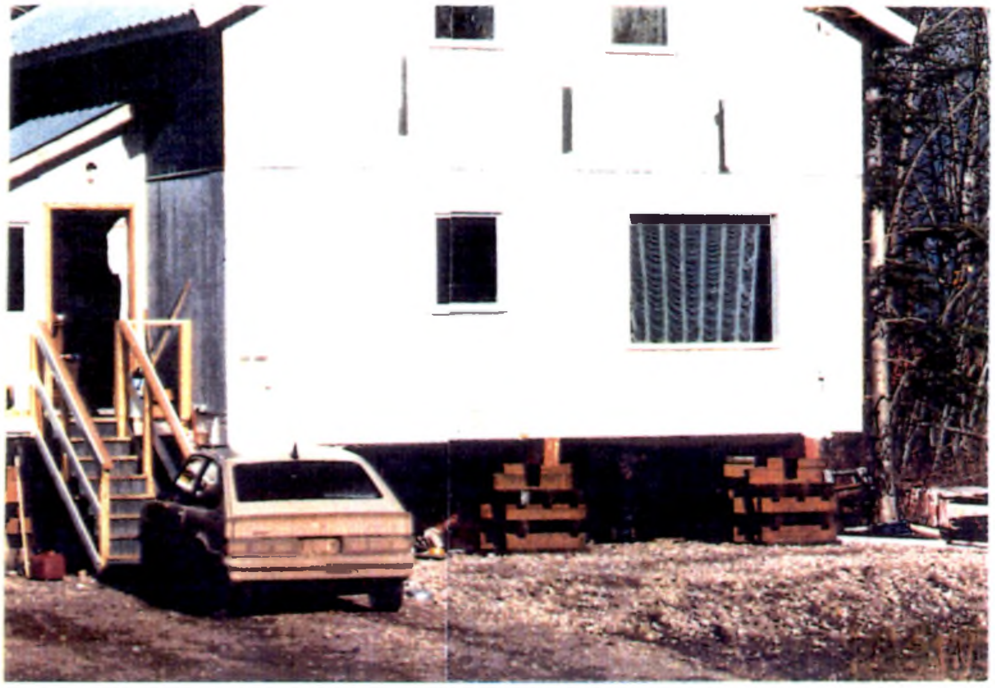
12

ADJACENT HOUSES

13

TYPICAL PLYWOOD SKIRT AROUND HOUSE FOUNDATION

14



TYPICAL TIMBER CRIB FOUNDATION

15

TYPICAL STEEL PIPE PILE FOUNDATION IN THE AREA

16

A P P E N D I X   F

PHOTOGRAPHS - FORT FRANKLIN

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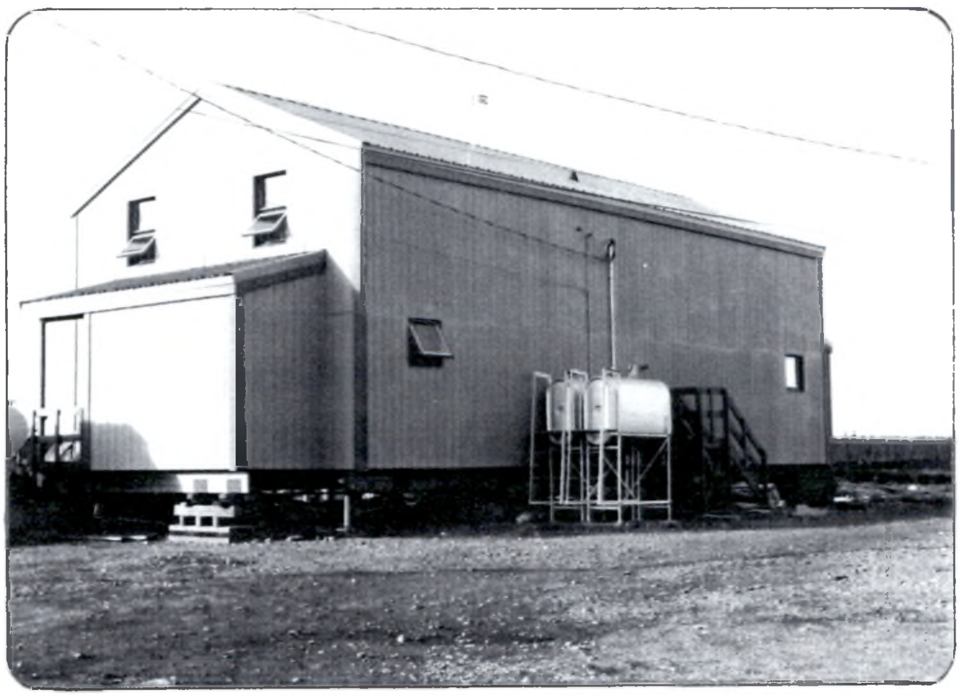
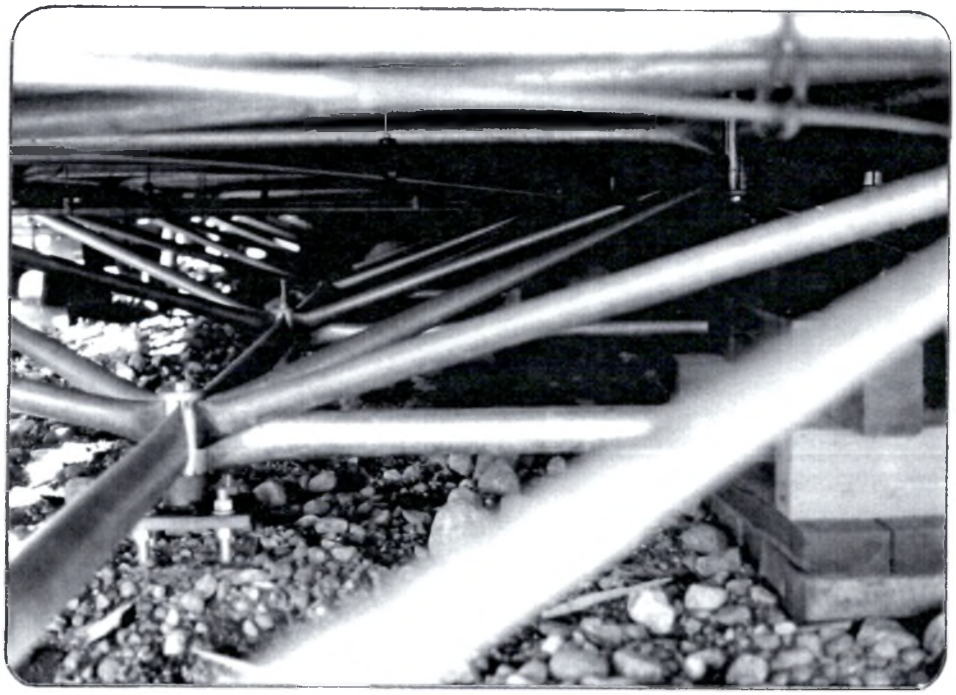
1

BUILDING 'A' 4-PLEX FORT FRANKLIN



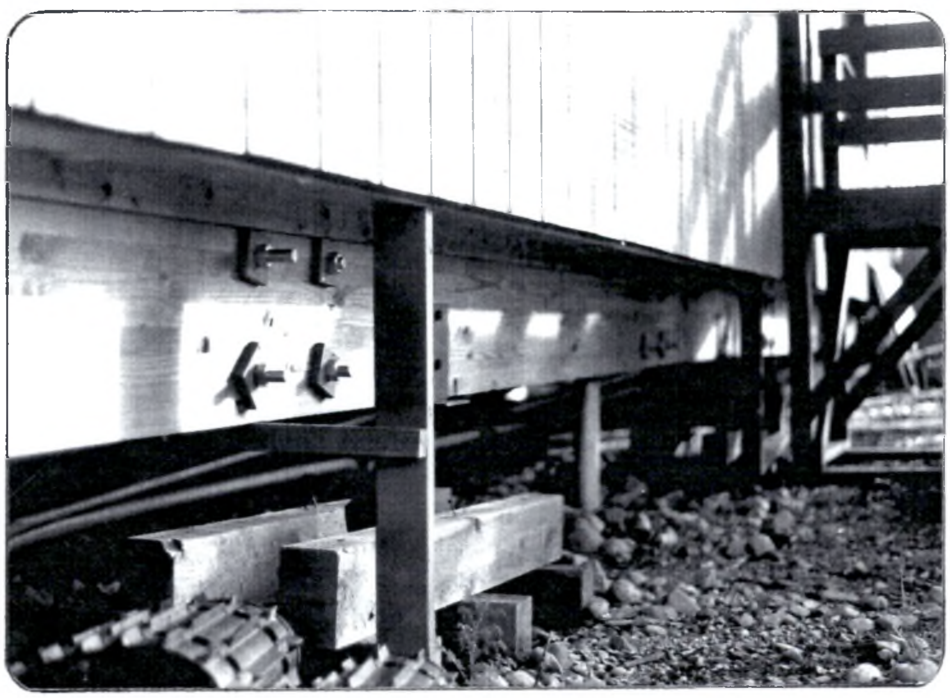
2

BUILDING 'C' DUPLEX FORT FRANKLIN



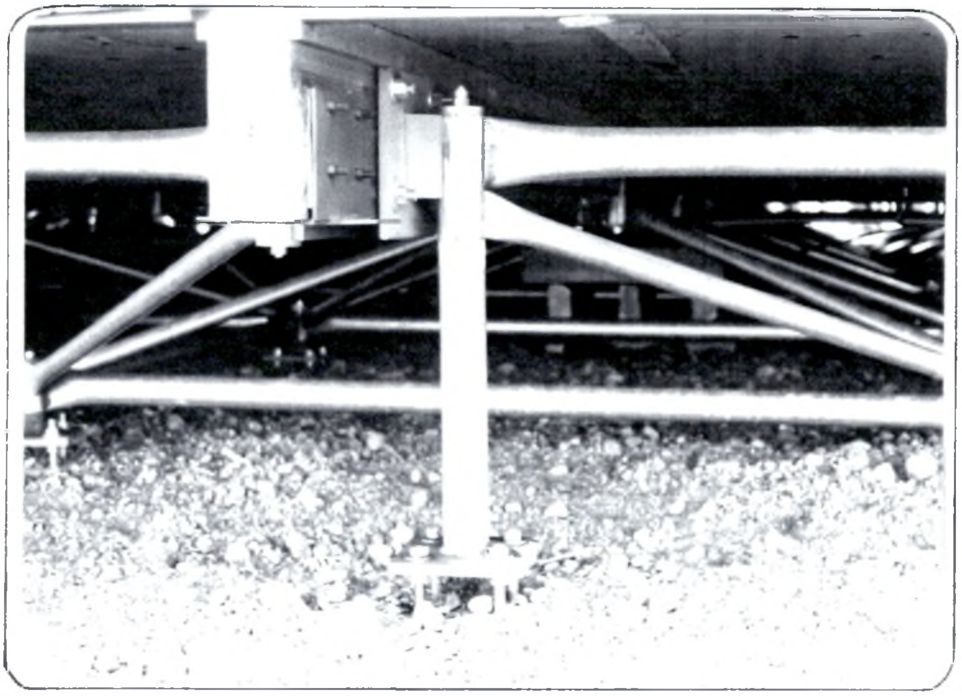
3

FOUNDATION FRAME



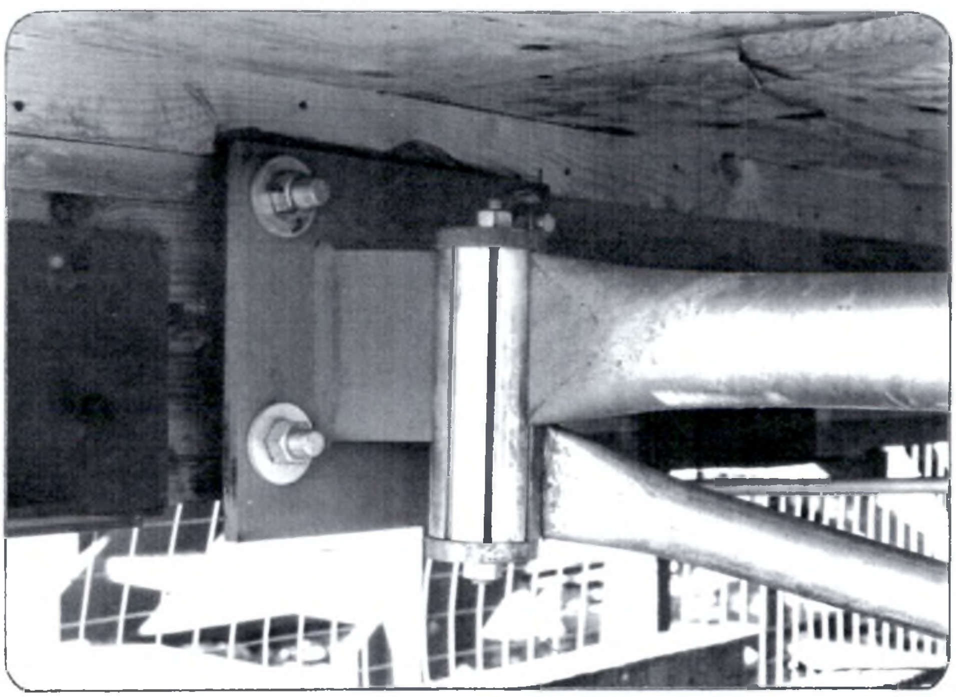
4

OLD TIMBER CRIB FOOTINGS



5

ADDITIONAL PERIMETER VERTICAL SUPPORT

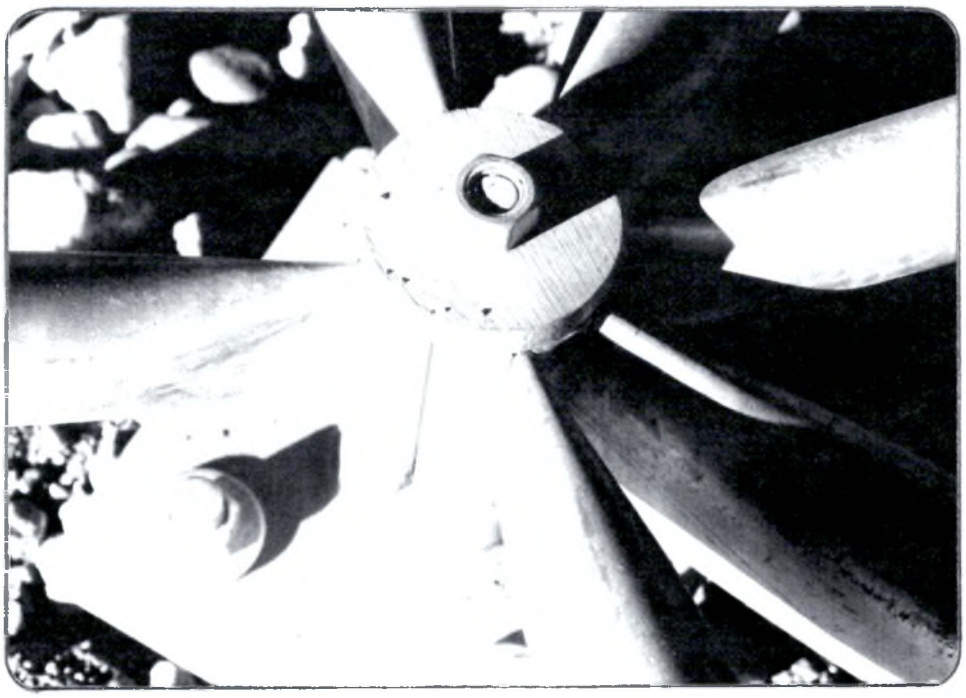


6

FRAME CONNECTION TO EXISTING BEAM

7

ADJUSTABLE BASEPLATE



8

TOP OF HUB

APPENDIX G

COST COMPARISONS

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COST COMPARISON OF HOUSE FOUNDATIONS IN HAY RIVER RESERVE

FOR STANDARD 1 STOREY 3 BEDROOM HOUSE

ITEM	MATERIALS & SHIPPING	LABOUR	TOTAL	REMARKS
SURFACE FOOTINGS				
3 ROWS OF 4-38X235(2X10) BUILT UP BEAMS	$1,000.00	$1,000.00	$2,000.00	
89 X 140 (4 X 6) PADS AND WEDGES	$2,000.00	$1,000.00	$3,000.00	
			$5,000.00	(A)
PILES				
3 ROWS OF 4-38X235(2X10) BUILT UP BEAMS	$1,000.00	$1,000.00	$2,000.00	
21 STEEL PIPE PILES AND CAPS	$7,000.00	$3,000.00	$10,000.00	
			$12,000.00	(B)
MULTIPOINT SPACE FRAME				
5 ROWS OF 3-38X140(2X6) BUILT UP BEAMS	$700.00	$500.00	$1,200.00	
METAL SPACE FRAME	$12,000.00	$2,000.00	$14,000.00	
			$15,200.00	

REMARKS :

(A) CAPITAL COST ONLY; LIFE CYCLE COST NOT INCLUDED.

B) COSTS BASED ON LARGE AMOUNT OF PIPES OBTAINED DIRECTLY BY THE GENERAL CONTRACTOR AND A NUMBER OF HOUSES WERE BUILT AT THE SAME TIME; NORMAL PILE FOUNDATION COST FOR A SINGLE HOUSE WOULD BE $ 18000.00 ; ADDITIONAL COST OF APPROX. $ 1000.00 FOR SOIL INVESTIGATION MAY BE REQUIRED.

A P P E N D I X   H

THURBER CONSULTANTS LTD.
REPORT AND SUPPLEMENT LETTER

Reid Crowther

THURBER CONSULTANTS LTD.
P.O. Box 2641, YELLOWKNIFE, N.W.T. X1A 2P9
Phone [403] 873-5901
Fax [403] 873-6387

File: 17-357-35

October 16, 1987

Reid Crowther & Partners Ltd.
17704 - 103 Avenue
Edmonton, Alberta
T5S 1J9

Attention: Mr. Ray Chan, P.Eng.

Dear Sir:

RE: HAY RIVER RESERVE - SPACE FRAME

This letter report is intended to convey our observations and impressions gleaned from a recent site visit to the noted project location in company with Mr. Rob Duncan of C.M.H.C. and yourself.

Our terms of reference as indicated by Mr. A. Isenegger during a meeting on October 5, 1987 were limited to field observations and professional opinion as requested by you. No subsurface investigation, field instrumentation and monitoring measurments of space frame movements or reaction to foundation conditions are required at this time. We understand that the funds available limit 1987/88 field monitoring to differential levels to be taken by your staff. Further instrumentation may be possible in subsequent years.

We enclose for your use several field photos taken at the time of our site visit. I believe it is clear from these photos that the space frame (a tubular aluminum structure) covers approximately 6 m by 12 m on the surface of a sand pad and is resting on 28 individual steel plate supports (Photo 1). Each of these support points is a 12 inch square by 3/4 inch thick steel plate carrying a cylindrical slotted upright piece which can be raised and/or lowered by adjusting threaded nuts (Photo 2). Most of the steel footings are bearing directly on the surface of the sand pad but several at the south end have been blocked up by 2 x 6 lumber (Photo 3) to achieve a level frame and still leave some room for future adjustments.

The sand pad is an uncompacted fill of fine brown sand in a loose state which ranges in height from about 1.2 m at the southeast corner to about 0.5 m at the northwest corner (Photo 4).

The sand has apparently been placed directly over the organic top soil after removal of the trees and brush by hand clearing.

The stratigraphy is assumed to be similar to that existing at the school site approximately 1 km to the north. This profile may be described as 6 m of ice rich clayey silt underlain by a dense frozen sand till with significnt gravel and coarser constituents. The till, which has a generally level surface at the school site, presented difficult pile driving conditions during school construction.

It is expected that the seasonal frost will penetrate the sand fill and underlying soil to a total depth of about 2 to 3 m, particularly if the depth of snow is not great over the site. It is unlikely that sufficient heat will be conducted from the house to the pad through the frame to prevent freezing of the ground.

On the basis of our observations of October 7, 1987 I would expect a reasonable allowable bearing pressure for the footings to be about 50 kPa. During the period of the year while the sand is frozen it will, of course, carry a much greater unit load. During the period of spring melt it may be rather lower depending upon the drainage conditions (i.e., if water is allowed to pond on the surface of the sand pad). In any event, we anticipate that the applied loads will, at times, exceed the above value resulting in significant settlement of some bearing points and redistribution of the load to other footings.

The sand fill has low to moderate frost susceptibility and is generally well drained, therefore significant frost heave is not expected. It is expected that any heave occuring between this date and April 1988 will be in the range of 0 to 50 mm and will be gradually distributed through time and space.

We anticipate that more abrupt movements will occur during the spring thaw. It is therefore recommended that the field monitoring be undertaken during November, March and May 1988. If budget limitations restrict the monitoring to two site visits we recommend that these take place during the spring immediately before and after spring thaw.

Alternative foundation systems common on the Hay River Reserve include steel pipe piling (Photo 5) and timber cribbing (Photo 6). These foundation types are used throughout the Northwest Territories for small structures and may perform satisfactorily if properly designed and constructed. Occasionally, however, light structures suffer from frost heave effects if piles are not properly anchored into bedrock or other dense medium. Further, cribbed foundations require continuous observation and conscientious maintenance to counteract the seasonal ground movements caused by frost action and thawing.

We trust this report meets your present requirments and will be pleased to participate further at your request.

Yours very truly,

THURBER CONSULTANTS LTD.
L.B. Smith, P.Eng.
Review Principal

G. Hollingshead, P.Eng.
Project Engineer

GH/dhm

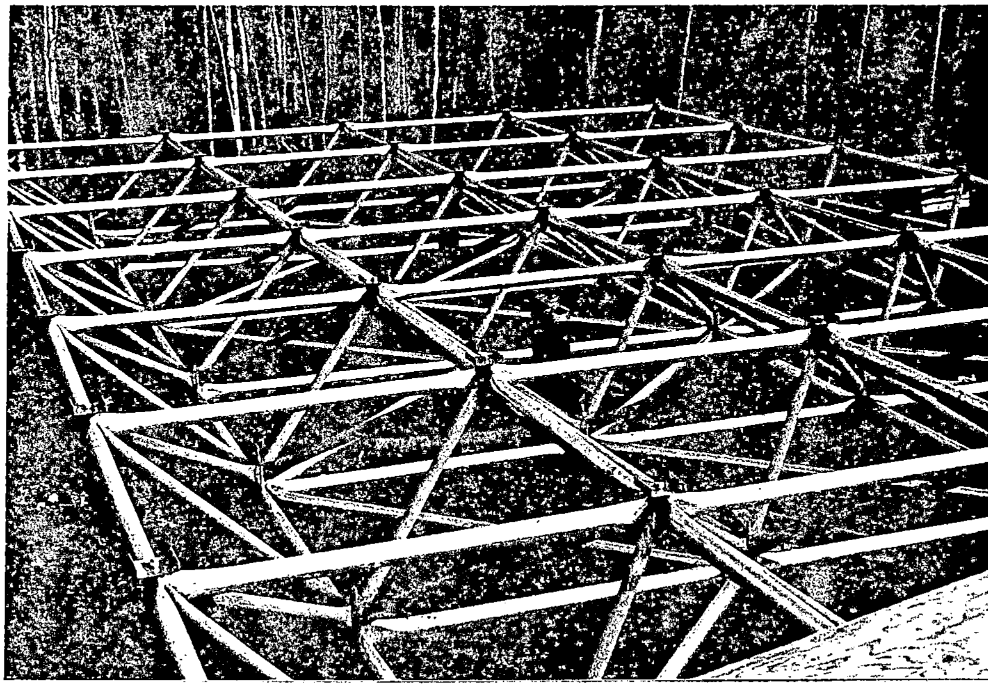


Photo 1 Overall View of Space Frame GWH 4-19

Photo 2 Lower chord of frame showing detail of joint and 12 inch square bearing plate GWH 3-17

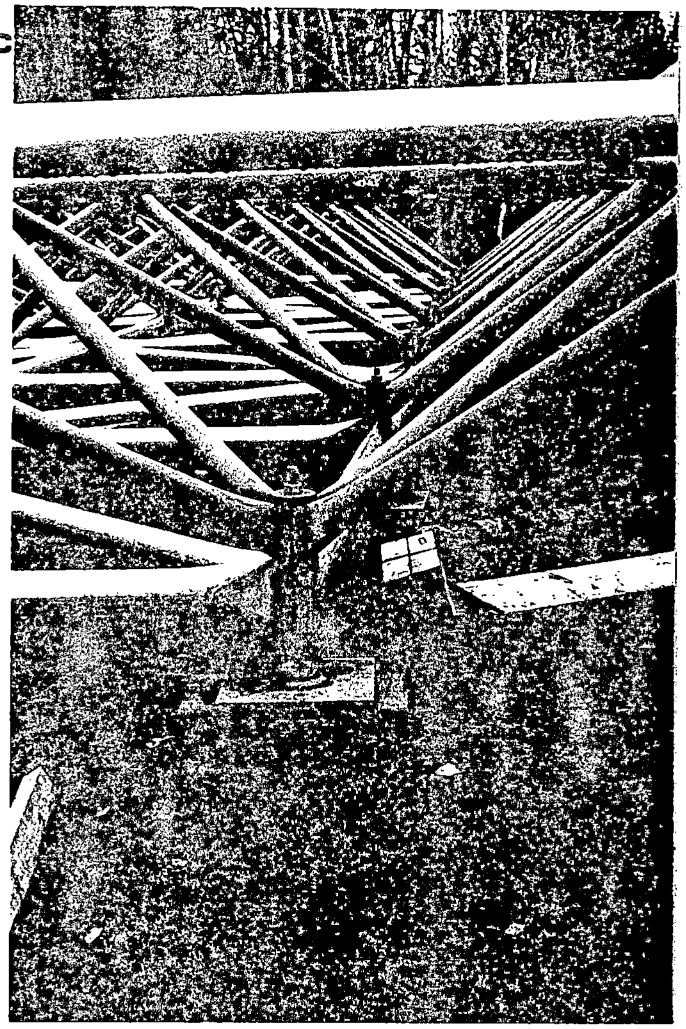


Photo 3 View showing levelling timber at southeast corner pad GWH 2-13

Photo 4 View (from drive) along east edge of 1.2 m high sand fill. Note organic top soil beneath fill. GWH 4-22

Photo 5 New house construction on steel pipe piles (100 mm dia. at 3m centres) GWH 5-24

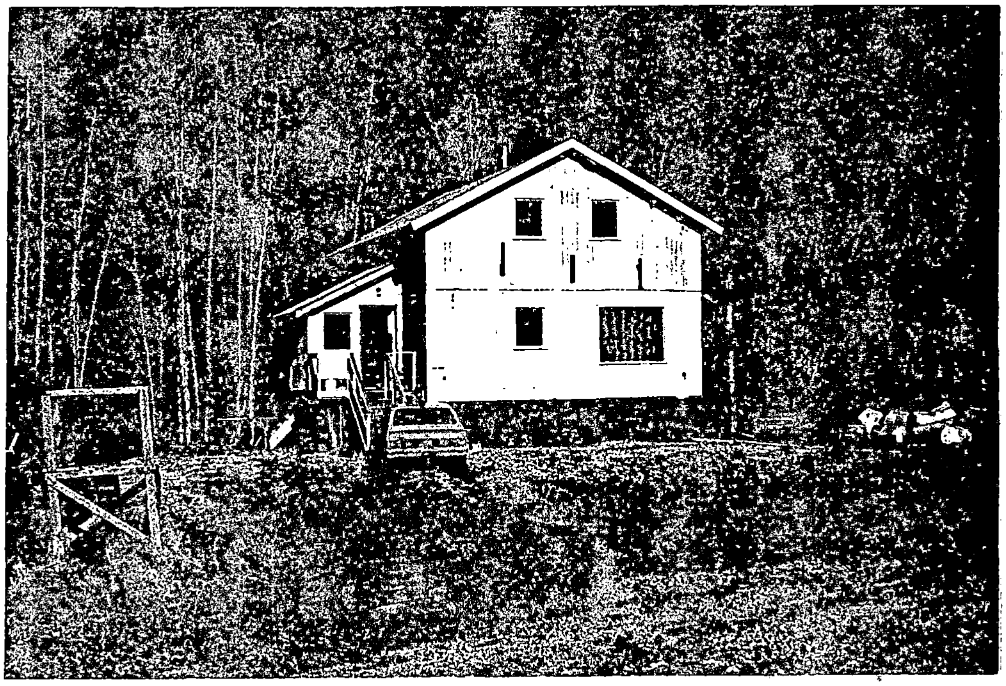


Photo 6 New house on timber crib foundation GWH 5-25

THURBER CONSULTANTS LTD.
P.O. Box 2641, YELLOWKNIFE, N.W.T. X1A 2P9
Phone (403) 873-5901
Fax (403) 873-6387

File: 17-357-35

April 25, 1988

Reid Crowther and Partners Ltd.
17704 - 103 Avenue
Edmonton, Alberta
T5S 1J9

Attention: Mr. Ray Chan, P.Eng.

Dear Sir:

HAY RIVER SPACE FRAME

Enclosed for use by CMHC are several thumbnail sketches of case hsitories. With regard to the sand pad at Hay River, I would comment as follows.

As a general rule, a properly designed and constructed (i.e. compacted) granular pad is a helpful element for shallow foundations in permafrost areas. The concrete or timber footings are then placed in or on this pad.

In theory, the objective of this approach is to minimize disturbance of the natural ground and thus enhance preservation of the ground thermal regime. (i.e., the permafrost). In many situations further north, the permafrost table may in fact be drawn up into the gravel pad and in this way "freeze in" and increase the stability of shallow foundations within the pad. This is often referred to as the "Greenland" type foundation. Seasonal movements are avoided (refer to Tuktoyaktuk Arena case history attached).

In reality, the permafrost regime is very much a site specific phenomenon; therefore, the pad concept is not generally applicable throughout the N.W.T.

For example, in the Hay River Region permafrost is very marginal at best and tends to be relatively deep. The sand pad used for the space frame base is therefore not a significant element with respect to permafrost preservation. It is useful to the extent that it provides a more uniform, level and workable ground surface, but will do little, if anything, to preserve the permafrost. On the other hand, if its presence avoids the need to excavate for sewage holding tanks, it may retard the rate of permafrost thaw and to this extent also it may be considered useful. For purely foundation reasons, however, a 300 mm thick sand pad would be equally successful at this location.

As a matter of interest, the Northern Region Headquarters (DND) in Yellowknife is housed in a temporary structure situated on a 1.8 m thick sand pad. The single story building is located over 30 m of ice rich sandy permafrost and has been relatively stable throughout its 25 year existence. It suffers annually from frost heave but the fragile Yellowknife permafrost (T = -0.6°C) has been preserved and therefore the pad has served its intended function. In the High Arctic, of course, pads are common and quite helpful as noted above.

Yours truly,

THURBER CONSULTANTS LTD.

L.B. Smith, P.Eng.
Review Principal

G.W. Hollingshead, P.Eng.
Project Engineer

Enclosure

GWH/dhm
17-35735.a25

APPENDIX J

SPACE FRAME MANUFACTURERS

Triodetic Building Products Ltd.
2753 Fenton Road
Ottawa, Ontario
K1G 3N3

Telephone: (613) 822-2922

Unistrut of Canada Ltd.
585 Finley Avenue
Ajax, Ontario
L1S 2E4

Telephone: (416) 683-8131

Artecal Exhibit and Displays
5885 Bessette Street
St. Laurent, Quebec
H4S 1P1

Telephone: (514) 332-2084

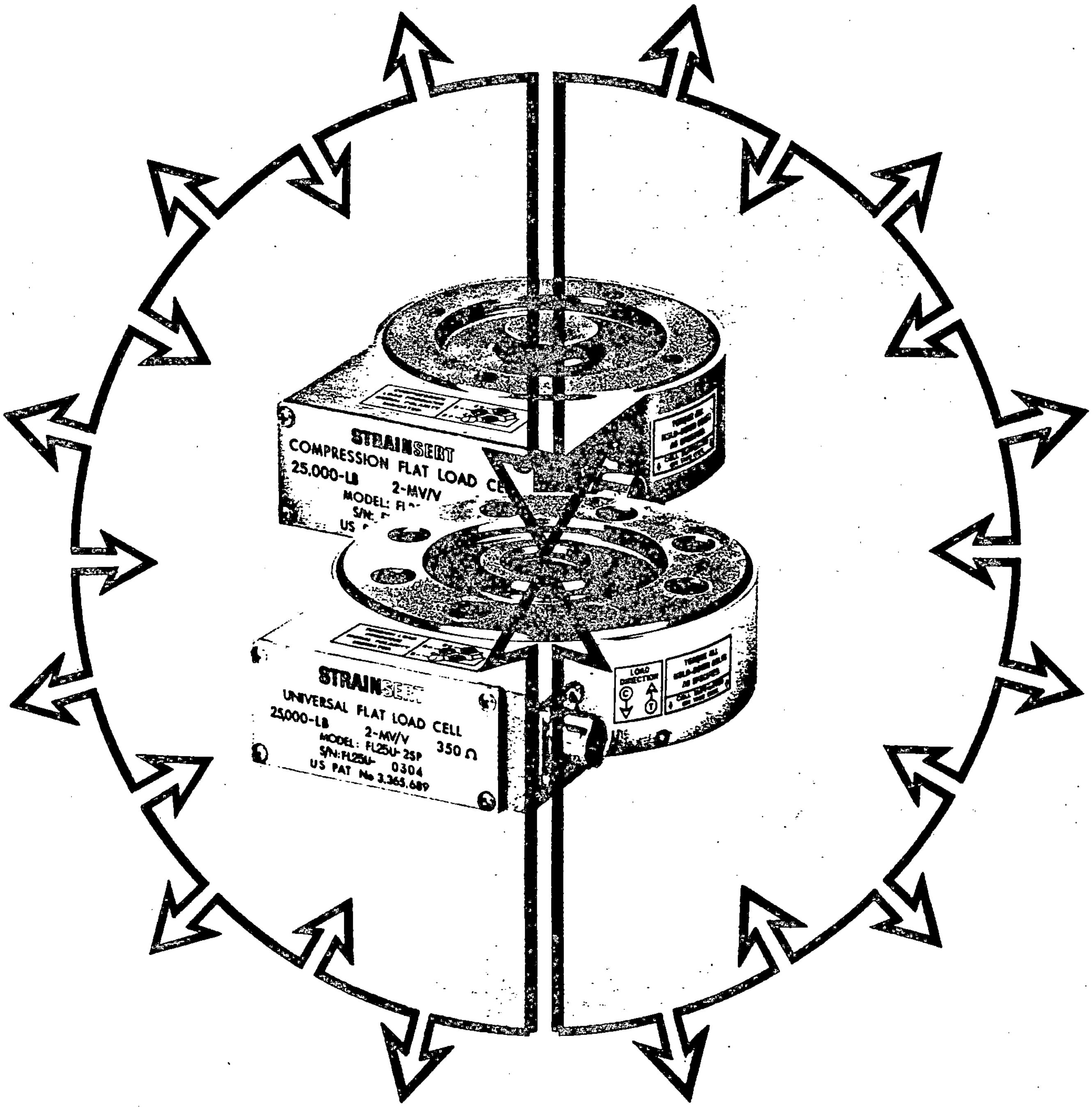
APPENDIX K

LOAD CELLS BROCHURES

Reid
Crowther

FLAT LOAD CELLS®

U.S. Pat. #3,365,689



Mechanical & Dynamic Properties

BROCHURE #365-4MP

STRAINSERT

MECHANICAL PROPERTIES OF FLAT LOAD CELLS

Deflection, Spring Rate, and Natural Frequencies for Universal and Compression Flat Load Cells are given in tabular form.

These mechanical properties of the load cells are based on the installation of Figure 1, in which the outer rim of the cell is clamped to a heavy, rigid base which deflects negligibly under load, and does not vibrate when excited by the load cell forces. The force P is applied axially at the center of the load cell.

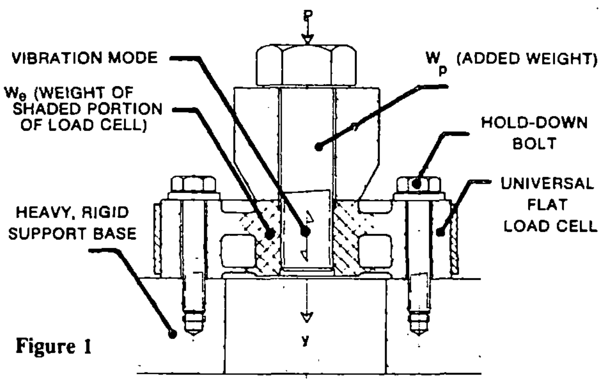


Figure 1

y, DEFLECTION, INCHES UNDER CAPACITY FORCE P LBS.

Deflection y represents the axial deflection of the cell under capacity load P.

The Spring Rate K = P/y is the Stiffness of the load cell in the axial direction, and is the ratio between the force P and deflection y.

The effective weight W_e is that portion of the load cell weight which is gray shaded in Figure 1. It consists of the weight of the center hub and inboard parts of the reduced section and diaphragm which vibrate at or near full amplitude when the load cell is dynamically excited. The outer rim of the load cell and adjacent parts (not shaded) are assumed to be motionless, since they are held by the heavy base. The effective vibrating weight of the load cell is different than shown, when its outer rim is flexibly supported and participates in the vibration.

The tabulated values of axial natural frequency f_c are those obtained when no weights W_b are attached to the hub of the load cell, which vibrates freely. By definition, this is the natural frequency of a single-degree-of-freedom system consisting of spring K and weight W_e. This is the highest possible axial natural frequency of a load cell installation, since any loading member will add mass to the center, hence, reduce the frequency.

In order to give an example of natural frequency reduction as weight is added to the hub, values of natural frequency f_p are listed for each load cell for the case when this additional weight W_p is equal to 0.001 P, as illustrated in Figure 1. Thus, the 50,000 pound capacity Universal Flat Load Cell with 2-mv/v sensitivity, has a natural frequency of 11,400 cps without any added weights, but this is reduced to a natural frequency f_p of 2,000 cps when a weight W_p of 50 pounds is added.

To determine the axial natural frequency f_x of any flat load cell system with any other added weight W_p (pounds) while rigidly supported as in Figure 1, the following equation may be used:

$$f_x = 3.13 \sqrt{\frac{K}{W_e + W_p}} \quad \text{cps.}$$

When the external weight W_p is relatively large, its motion may have to be restricted to the axial vibration mode by means of suitable guides. If not, natural frequencies of lateral modes could possibly be lower than those tabulated.

All tabulated values are obtained by analysis, and expected accuracy is within 15 to 20 percent.

EXTRANEOUS LOADING CAPACITIES OF UNIVERSAL FLAT LOAD CELLS

The Universal Flat Load Cells are designed to withstand extraneous loadings, in addition to the measured axial force P. Some typical extraneous loadings are tabulated, and are identified in Figure 2. These are lateral loads S_0 (along the top of the cell), S_1 (acting 1-inch above the top of the cell) and S_4 (acting 4-inches above the top of the cell). Also shown are bending moment M_b and torque M_t, applied to the center hub of the cell. It is assumed that any one of these would be applied individually, and not in combination with each other.

The tabulated values of extraneous loadings, applied individually will not cause permanent damage to the load cells. Allowable extraneous loadings are half the values tabulated if applied in conjunction with other extraneous loads or measured load P.

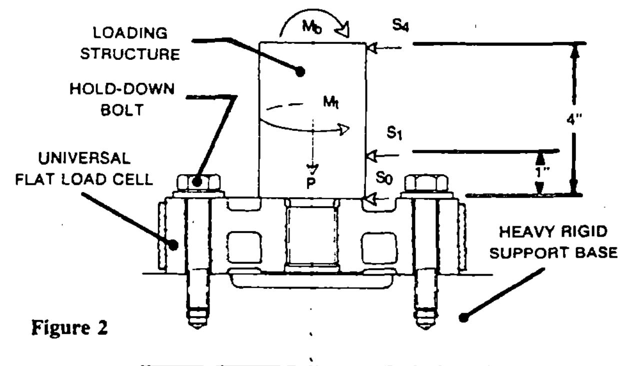
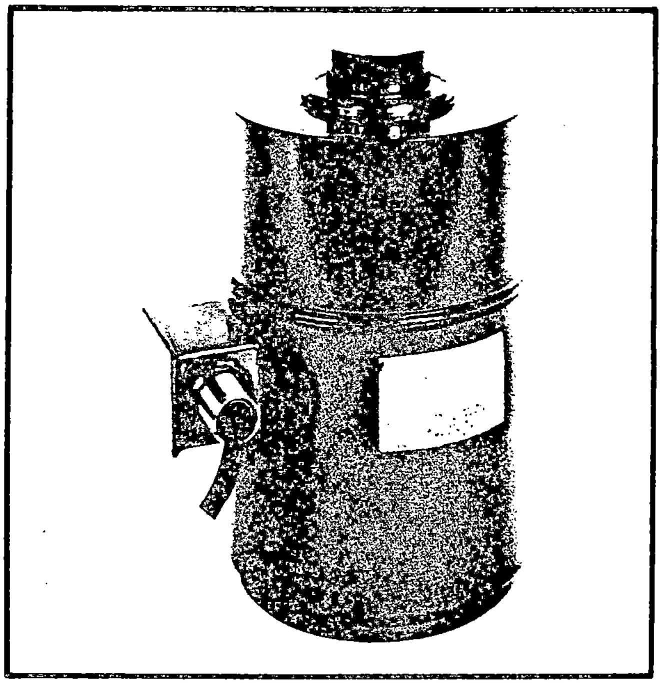


Figure 2

P, FORCE MEASURED BY LOAD CELL
S_0, S_1, S , TYPICAL SIDE FORCES
M_b. BENDING MOMENT
M_t. TORQUE ABOUT AXIS OF LOAD CELL
} EXTRANEOUS LOADINGS

TRANSDUCERS, Inc.

14030 Bolsa Lane • Cerritos, California 90701-5195 • (714) 739-1991
TWX: 910-596-1433 • 1 (800) 621-3109 Toll Free Number (Outside of California)



MODEL 92 HERMETICALLY SEALED COMPRESSION LOAD CELL

FEATURES:

- Capacities from 5K to 200K pounds
- PTB and DoT approved**
- Optional stainless steel housing
- True hermetic sealing
- Available in 2 or 3mV/V outputs
- Optional dual bridge
- Operational from −65°F to +200°F
- Factory Mutual approval guarantees intrinsic safety*
- Exceeds NEW 1986 Scales Code**
- Lightning protection std on 50K capacity and above

DESCRIPTION:

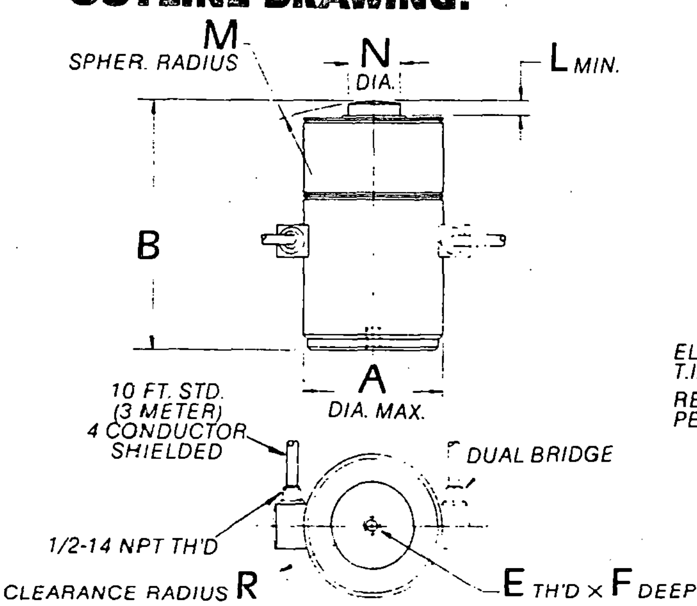
The Model 92 is a high profile compression type load cell. Its high accuracy, hermetic sealing and wide capacity range make it an excellent choice for truck, tank, track and hopper applications. The 92 load cell's precision, long life and dependability are partly the result of responsible quality control and conservative engineering. These disciplines are part of the capability TI has developed from making load cells that have now been in service for over 25 years. Also contributing to its superior performance are true hermetic sealing which requires all seals to be soldered or welded metal to metal or bonded glass to metal **and** fully linearized columns. The 92 is Factory Mutual approved, approved by PTB and DoT and exceeds the NEW H-44 Class IIIL requirements. These are a few of the reasons why user satisfaction is virtually guaranteed in the most stringent applications.

*FACTORY MUTUAL SYSTEM approved. All Transducers' load cells have been tested and approved as intrinsically safe by Factory Mutual Research when installed with approved barrier strip.
**PTB and DoT are European metrological agencies.

TYPICAL SPECIFICATIONS: MODEL 92

Standard Capacities (lbs.)	5K, 10K, 20K, 25K, 50K, 100K, 150K, 200K
Metric Equivalents (Approx.)	2.3t, 4.5t, 9.1t, 11t, 23t, 45t, 68t, 91t
Excitation (VDC)	10 Nom., 15 Max.
Rated Output (mV/V)	2 ±0.1% (3 ±0.1% optional)
Zero Balance (Max.)	1% of Full Scale
Non-Linearity (Max.)	.05% of Full Scale
Hysteresis (Max.)	.02% of Full Scale (.03% for 3mV/V option)
Non-Repeatability (Max.)	.01% of Full Scale (.02% for 3mV/V option)
Creep (Max.)	.03% of load in 20 Minutes
Temperature Sensitivity (Max.)	
Output	.0008% of load/°F or .0015%/°C
Zero	.0015% of Full Scale/°F or .0027%/°C
Resistance (Input and Output, ohms)	350 ±1.0%
Seal	Hermetic
Operating Temperature Range	−65°F to +200°F or −50°C to +90°C
Compensated Temperature Range	0°F to +150°F or −15°C to +65°C
Safe Overload	150% of Full Scale
Ultimate Overload	300% of Full Scale (200% for 3mV/V option)
Max. Side Load W/O Damage	10% of Full Scale

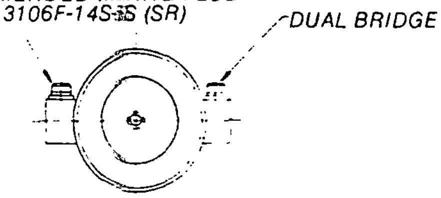
OUTLINE DRAWING:



CABLE VERSION STANDARD
−10P1
−10Y1-DUAL BRIDGE OPTION

STANDARD BRIDGE TERMINATION

FUNCTION	CABLE COLOR	CONNECTOR PIN (R CAL)	CONNECTOR PIN (SENSE)
Input +	Red	A	A & F
Output +	Green	B	B
Output −	White	C & F	C
Input −	Black	D & E	D & E
Shield	Orange		



CONNECTOR VERSION OPTIONAL
−C2P1 (R CAL) −C2Y1
−C1-1 (SENSE) −C1Y1 } DUAL BRIDGE OPTION

DIMENSIONS — inch & (mm.)

CAPACITY lbs. (tons)	A	B	E	F	L	M	N	R	DEFLECTION lbs. (kg)	WEIGHT
5K, 10K (2.3, 4.5)	3.53 (89.7)	4.00 (101.6)	1/2-20 UNF	.50 (12.7)	.40 (10.2)	[illegible].0 ([illegible]2.4)	1.0 (25.4)	3.5 (88.9)	.003 max. (.1)	5 (2.3)
20K, 25K (9.1, 11)	3.53 (89.7)	5.00 (127.0)	1/2-20 UNF	.40 (10.2)	.40 (10.2)	[illegible].0 ([illegible]2.4)	1.0 (25.4)	3.5 (88.9)	.004 max. (.1)	6 (2.7)
50K (23)	4.33 (110.0)	6.00 (152.4)	3/4-16 UNF	.56 (14.2)	.50 (12.7)	[illegible].0 ([illegible]2.4)	1.50 (38.1)	3.8 (96.5)	.004 max. (.1)	9 (4.1)
100K (45)	5.03 (127.8)	8.50 (215.9)	3/4-16 UNF	.56 (14.2)	.63 (16.0)	[illegible].0 ([illegible]4.8)	1.75 (44.5)	4.0 (101.6)	.006 max. (.2)	18 (8.2)
150K, 200K (68, 91)	6.53 (165.9)	11.13 (282.7)	3/4-16 UNF	.56 (14.2)	.63 (16.0)	[illegible]0 ([illegible]8)	2.50 (63.5)	4.8 (121.9)	.01 max. (.3)	45 (20)

ORDERING INFORMATION:

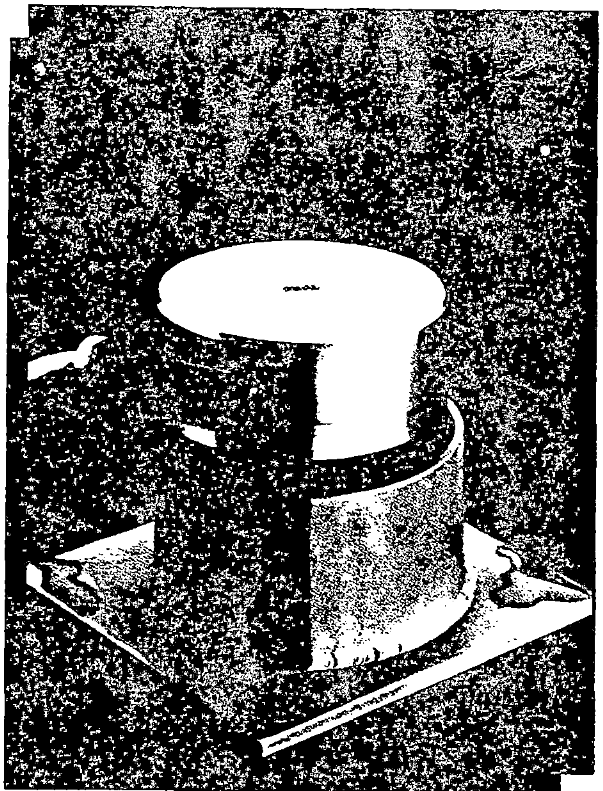
Specify Model 92 (93 for 3mV/V), capacity and options as shown above.

7/86 3K

ALL SPECIFICATIONS SUBJECT TO CHANGE WITHOUT NOTICE.

Kistler-Morse®

Load Disc™ Sensor



☐ Durable, Stainless Steel Construction
☐ Low Profile
☐ Easy to Install
☐ Accuracy of 0.25% for Process Weighing Applications

A Low Profile Load Cell for Washdown Environments

The Load Disc sensor is a unique, low profile, electronic load cell that determines the weight of material stored in bins, hoppers, tanks or other storage vessels. It is designed for applications requiring a rugged load sensor that can stand up to constant washdowns or contact with caustic cleaning agents.

Withstands Constant Washdowns
The Load Disc sensor is manufactured of stainless steel for durable long-lasting protection. It is sealed to protect against moisture and caustic cleaning agents used during washdowns.

Universal Adaptability
Unique installation hardware insures that the Load Disc sensor will fit under most vessel supports and produce an accurate weight signal. For vessels with spun ball bottomed legs, a load centering ring positions the load at the center of the Load Disc sensor. For gussets and other vessel supports, an adjustable load button is used with a load centering ring to properly position the load. In all applications a base retainer plate and support bearing hold the sensor securely under the vessel support.

Unique Operating Design
In operation, the top of the Load Disc sensor acts as a diaphragm, deflecting from the weight of the vessel and the vessel contents. This deflection results in a two-dimensional "stretching" of the diaphragm surface which is measured by a patented biaxial strain sensor. An electrical signal proportional to the weight in the vessel is produced. This signal is conditioned and the weight or level displayed on a readout.

Easy Installation
The Load Disc sensor has a very low installed height (less than 2 inches [50 mm]) and comes complete with all mounting hardware. Installing the Load Disc sensor is simply a matter of raising the vessel slightly, inserting the Load Disc sensor with hardware under the supports, and lowering the vessel. The base retainer plate may be bolted to the foundation to prevent vessel movement. Most applications do not require the use of checking hardware.

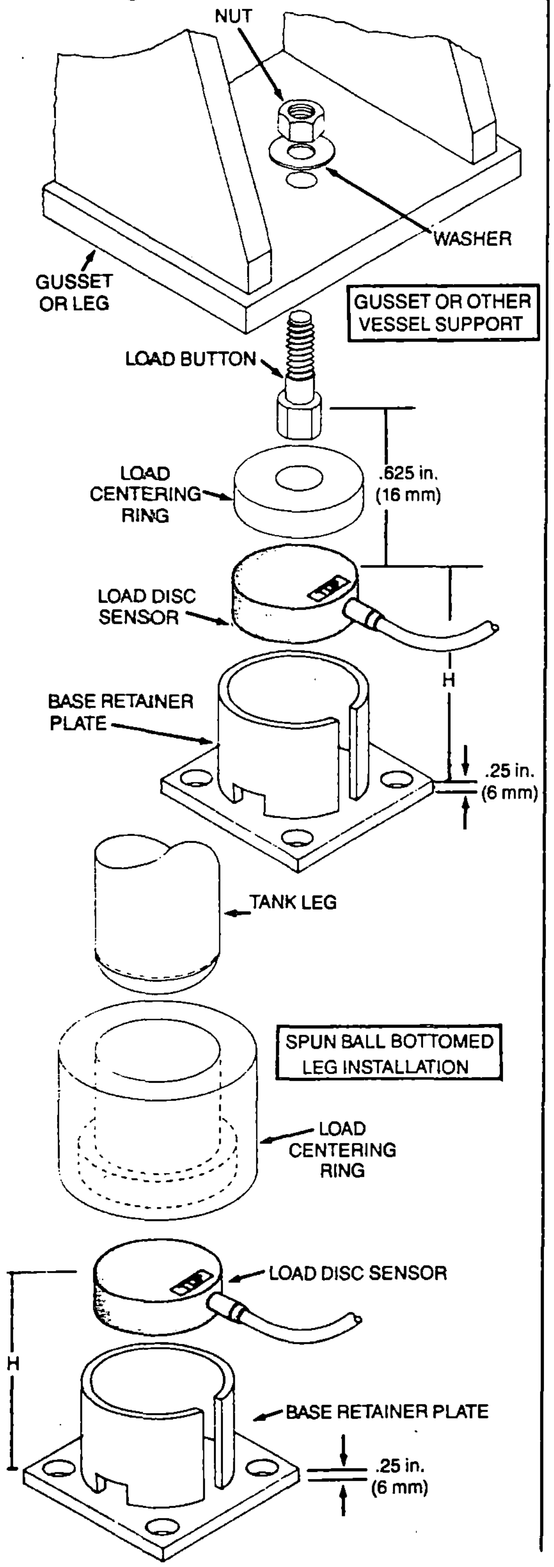
High Level Output
Semiconductor strain gage technology provides a very high electrical output. This output is further enhanced by the structural design of the gage, resulting in a full scale output of 275 mV @ 12 V excitation. This high output and standard 3-conductor cable provide an effective noise-immune system with a minimum of connections.

Many Output/Display Options
A variety of electronic instruments is available to condition, display, and transmit the weight signal from the Load Disc sensor. These include analog, digital, and LED bar graph indicators; batch controllers; and isolated 4-20 mA current transmitters. The conditioning electronics may be located up to 2,000 feet (600 m) from the Load Disc sensor.

Proven Performance
The Load Disc sensor is ideal for use with stainless steel batching, blending, and storage vessels where accurate inventory information is required. The Load Disc sensor can also be used with many other types of steel structures and is currently installed on vessels in the food, beverage, dairy, wine, chemical, and pharmaceutical industries. It is available in weight ranges from 1,000 to 10,000 pounds (450 to 4,500 kg) per support.

KM 20-287, 1/86

Mounting Dimensions



Specifications — Load Disc™ Sensor

INPUT

Excitation Voltage

Standard	12 Vdc
Maximum	30 Vdc
Sensor Load Limit (Electrical Integrity)	1.5 times rated load

OUTPUT (for 12V Excitation)

Rated Output	275 mV at rated load
No Load Output	± 25 mV maximum
Combined Nonlinearity and Hysteresis	± 0.10% rated load
Repeatability	0.10% rated load

ENVIRONMENTAL

Operating Temperature Range	–30° to 140° (–35° to 60°C)
Compensated Temperature Range	0° to 100°F (–18° to 38°C)
Temperature Sensitivity Shift	0.02%/°F (ΔT = 50°F) (0.04%/°C [ΔT = 30°C])
Temperature Zero Shift	± 5 mV/100°F (± 5 mV/56°C)
Humidity	95%

PHYSICAL

Cable	3-conductor, 20 gauge. 7 feet (2 m) long with junction box.
Material	17-4PH stainless steel

Ordering Information Table

MODEL NO.	RATED LOAD lb	RATED LOAD kg	DIAMETER in	DIAMETER mm	(H) HEIGHT in	(H) HEIGHT mm	SHIPPING WEIGHT lb	SHIPPING WEIGHT kg
D1-100D	1,000	450	2.75	70	0.815	21	6	2.7
D1-200D	2,000	900	2.75	70	0.815	21	6	2.7
D1-500D	5,000	2,250	2.75	70	1.05	27	6	2.7
D1-010K	10,000	4,500	2.75	70	1.14	29	6	2.7

Kistler-Morse manufactures a complete line of industrial weighing and level measurement systems. For more details, contact:

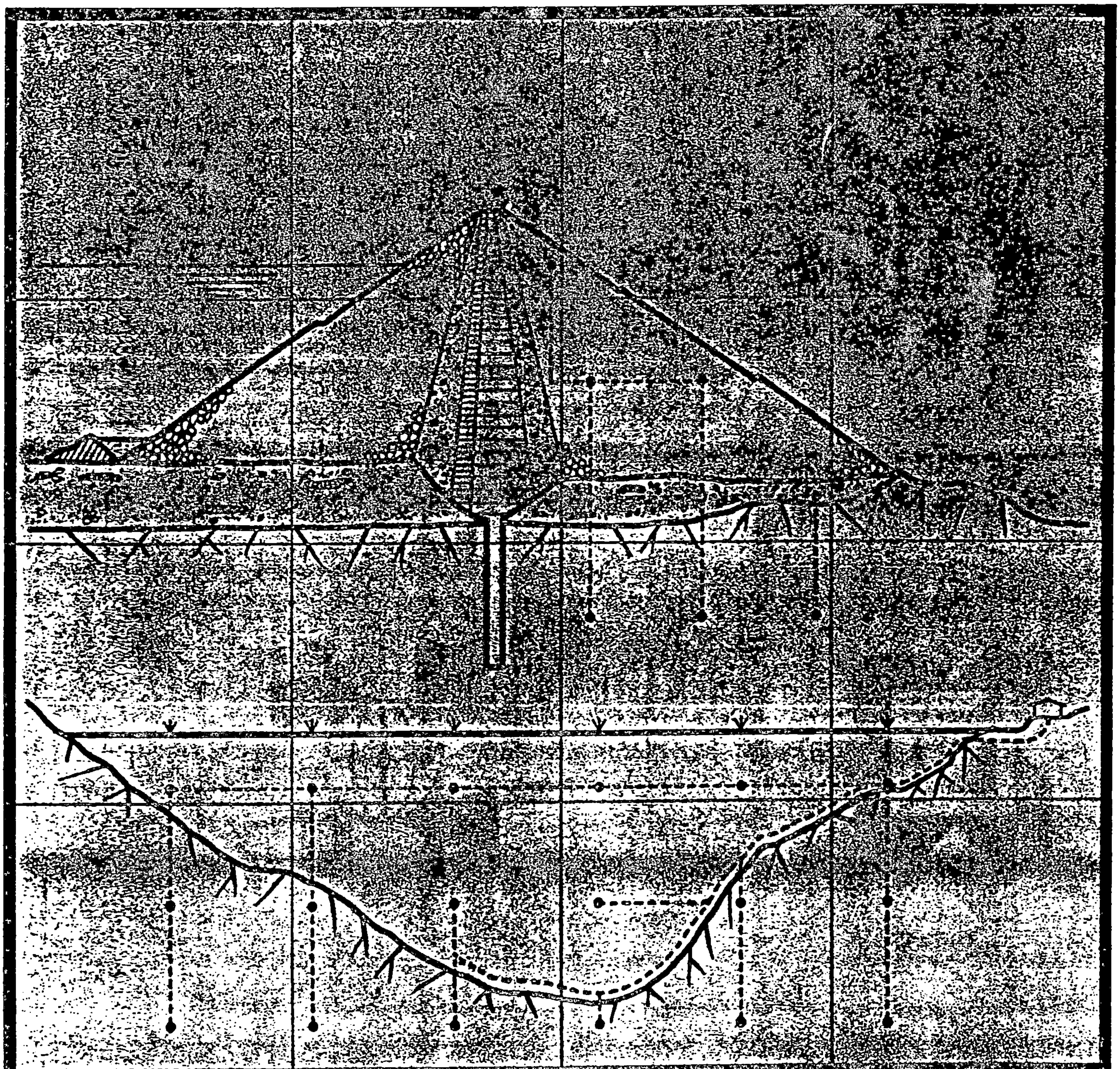
Kistler-Morse®

Corporate Office 10201 Willows Road N.E., P.O. Box 3009, Redmond, WA 98073
Phone: 206/881-8000, 800/426-9010; Telex: 15-2223

European Office Rucaplein 531, B-2610 Antwerp, BELGIUM
Phone: 32 3 218-9999; Telex: 73178

GLÖTZL MEASUREMENT SYSTEMS

TERRAMETRICS



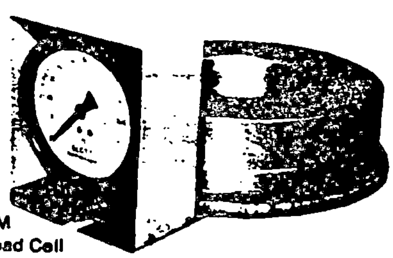
LOAD CELLS

(U.S. Patent No. 3,978,722)

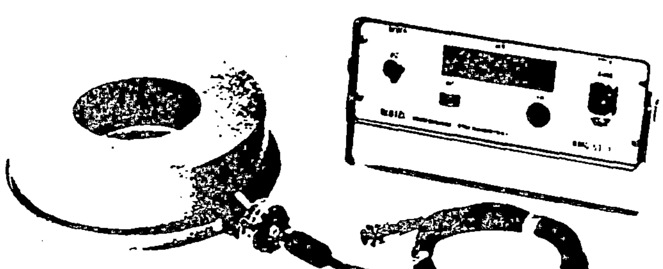
Adequate load resolution and long-term stability are only two considerations of load cell instrumentation. Other factors include the ability to resolve eccentric loads, and sufficient load capacity to withstand proof loading at up to 150 percent of working loads. Cells should also be free from temperature-induced errors, particularly when exposed to outdoor temperature variations. Finally, cells should be simple to read out, and should require relatively little computation to convert the raw data to actual loads.

Glötzl Hydraulic Load Cells provide excellent eccentric load resolution and overload capacity. An attached pressure gauge or a standard Glötzl bypass valve suitable for remote applications are used for readout. Temperature effects are slight, due to the internal construction of the cells, the small volume of fluid, and the heat-sinking capability of the massive bearing plate structures.

The Glötzl cells have excellent long-term stability, and when properly rated cells are selected for the particular load ranges anticipated, they are subject to negligible wear or other deterioration.



K100A105M
Tieback Load Cell



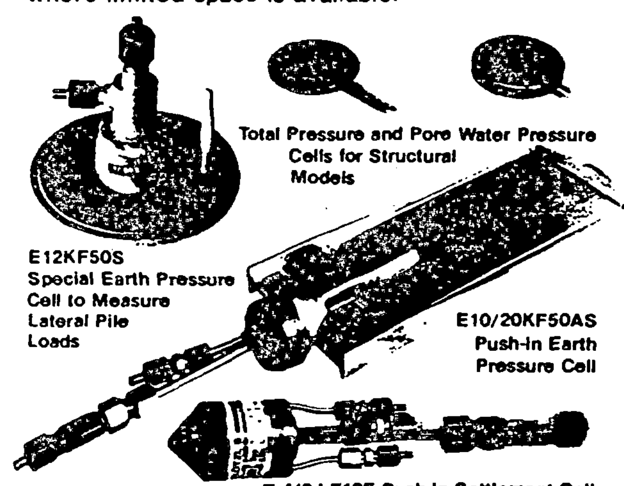
M1ALR16D
Tieback Load Cell with Remote Digital Readout

SPECIAL CELLS

Other Glötzl instruments are available for specialized application needs not met by standard cells.

- **Settlement Cells** measure settlement under structures and compaction and differential compaction in embankments. These cells utilize components of the Glötzl piezometer, and are read out using any of the regular Glötzl hand or semi-automatic pneumatic or hydraulic pumps.
- **Push-in Earth Pressure Cells** are used for measurements where a minimal disturbance of the stress field is desired.
- **Very Small Cells** are available for measuring earth pressure and pore water pressure in structural models.
- **Concrete Form Cells** are used for measuring the pressure on concrete forms.

A variety of valve placement configurations is available for standard and special cells, permitting the optimum cell arrangement in applications where limited space is available.



Total Pressure and Pore Water Pressure Cells for Structural Models

E12KF50S
Special Earth Pressure Cell to Measure Lateral Pile Loads

E10/20KF50AS
Push-In Earth Pressure Cell

T 4/8 LF12E Push-In Settlement Cell