MFG: MULLIGAN ENTERPRISES
NAME: STAR FIRE
TYPE: NON-KIDDIE



# DESIGN ANALYSIS

# OF

# STAR FIRE AMUSEMENT RIDE

Mulligan Enterprise
Gibsonton, Florida

September 30, 1991


Prepared By: R. Harris, P.E.

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September 30, 1991

**REPORT TO:** Clyde Mulligan
Mulligan Enterprise

**FROM:** R.D. Harris, P.E.
Engineering Design & Testing Corp.

**SUBJECT:** Design Analysis of Star Fire Amusement Ride
ED&T File Number: 3328-5939

An updated version of an amusement ride, originally called the Saturn 6, is under construction at Mulligan Enterprise in Gibsonton, Florida. The new version of the ride is to be called the Star Fire. The purpose of this investigation has been to perform an engineering analysis and certification of the new design.

This report is divided into sections as follows:

A. Summary Statement
B. Specifications
C. References
D. Analytical Summary

Appendices I. Calculations
II. Excerpts from References
III. Selected Drawings

## A. SUMMARY STATEMENT

The Star Fire amusement ride is a mechanism containing six (6) passenger cars at the ends of six (6) approximately 20 ft. arms. Each car holds a maximum of four (4) adult passengers. The arms rotate about a fixed center at 12 rpm. As they rotate, centripetal acceleration causes the passenger cars to rise at the ends of the swing arms. A vertical hydraulic lift system assists the uplift and applies a cyclic vertical motion. Appendix III contains general arrangement drawings of the ride under examination.

The analysis of this ride design has been performed based on fabrication drawings provided by Mulligan Enterprise. Key dimensions and structural shapes have been field verified by ED&T personnel at Mulligan's fabrication shop in Gibsonton, Florida.

The combined rotary and vertical motions of the ride result in a complex kinematic situation. For ease of analysis, extremely conservative simplifying assumptions have been made. For example, it has been assumed that all acceleration components coincide in both direction and time. The worst possible case of passenger load imbalances has been considered.

Also for ease of analysis, it has been conservatively assumed that all steel materials, including bolts and pins, are mild carbon steel. In only one case, the flanged connections for the central tower support, it was necessary to use the material properties of the actually used SAE Grade 5 bolts in order to satisfy design requirements. It is noted that this is based on an extremely conservative load development.

The results of this analysis show that the ride is adequately designed under all anticipated conditions of passenger load and that the ride is stable under operating conditions above the maximum wind design conditions recommended in the continental United States of 140 mph.

## B. SPECIFICATIONS

| | | |
|---|---|---|
| Gross Weight | | - 45,000 lbs. |
| Nominal Seating Capacity | | - Four Adults per Car<br>Six Cars per Ride |
| Horizontal Rotation | | - 12 rpm |
| Vertical Lift Hydraulics: | | |
| Pump: | Flow | - 47 gpm |
| | Pressure | - 650 psig (controlled)<br>- 1000 psig (relieved) |
| Cylinder: | Bore | - 4 in. |
| | Rod Diameter | - 2 in. |
| | Stroke | - 60 in. |

## C. REFERENCES

1. "The Design and Manufacture of Amusement Rides and Devices", ASTM F 1159, American Society for Testing and Materials, 1988

2. Stress, Strain,and Strength, Juvinall, McGraw-Hill, 1967

3. "Structural Steel", ASTM A36, American Society for Testing and Materials, 1984

4. Mark's Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw-Hill, 1978

5. Manual of Steel Construction, Eighth Edition, American Institute of Steel Construction, 1980

6. The Pressure Vessel Handbook, Fourth Edition, 1977

7. "Steel Fasteners", SAE J429, Society of Automotive Engineers, 1980

## D. ANALYTICAL SUMMARY

### 1. HYDRAULIC LIFT SYSTEM

A centrally mounted hydraulic cylinder acts to apply a cyclic vertical component to the passenger car movements. The cylinder lifts by lever action in the pull mode. Based on the system specifications, the following data is obtained:

Maximum Cylinder Velocity - 1.6 ft/sec

Hydraulic Force - 6123 lb. normal
(based on controlled pressure)

- 9429 lb. maximum
(based on relief valve settings)

### 2. KINEMATICS

The kinematic motion of this amusement ride is modelled as a 4-bar slider-crank linkage with a superimposed rotation about the slider. This results in an extremely complex motion involving rotations and accelerations in both the horizontal and vertical planes.

A time dependent analysis of such a mechanism is virtually impossible without the use of finite element computer modelling. However, it is possible to manually calculate the motions and accelerations of the individual motion components separately. These calculations have been performed. The conservative assumption has then been made that all accelerations act on the system masses in a manner coincident in direction

and time with results as follows:

| | | |
|---|---|---|
| Masses: | Car | - 9.3 slugs |
| | Cradle | - 7.8 slugs |
| | Passengers | - 21.1 slugs (4 adults) |
| | Total | 38.2 slugs |

Normal Acceleration, Horizontal Plane - 42.5 ft/sec-sec

It is shown that the hydraulic lift cylinder does not have sufficient force to overcome gravitational accelerations. Therefore, essentially all vertical plane accelerations will be components of the horizontal acceleration.

Therefore:

Maximum Total Acceleration = 42.5 ft/sec-sec
(gravity not included)

3. PASSENGER FORCES

The peak accelerations and forces will occur when the ride is at its highest point. The diagram on page 8 of the calculations in Appendix I illustrates the force vectors acting on a passenger in this orientation, including gravity.

The force vectors applied to a passenger due to rotational acceleration consist of a component of magnitude 1.27 times the passenger's weight normal to the car seat and a 0.34 times weight force acting upward against gravity. Including gravity, a passenger will experience a total force of 1.4 times his or her weight. The direction of this force is such as to tend to force the passenger more firmly into the car seat.

## 4. ALLOWABLE STRESSES

Maximum allowable stresses are calculated for shear and tensile stresses under both static and cyclic load conditions. It is assumed that all steel materials, including bolts and pins, are mild carbon steel corresponding to ASTM A36 structural steel. It is assumed that all structural aluminum material corresponds to alloy 6061-T6. The allowable stresses for static loads are calculated based on the Maximum Shear Stress theory of failure with safety factor of 2.0. The allowable stresses for cyclic loads are based on classical fatigue methods, with factors included for size, bending loads, and machined surfaces. Stress concentrations are treated individually as each component is analyzed. The resulting allowable stresses are as follows:

| | Static Loads | | Cyclic Loads | |
|---|---|---|---|---|
| Material | Tensile | Shear | Tensile | Shear |
| Carbon Steel | 18,000 psi | 9,000 psi | 18,800 psi | 12,100 psi |
| Aluminum | 20,000 | 10,000 | 11,650 | 7,500 |

## 5. STRESSES

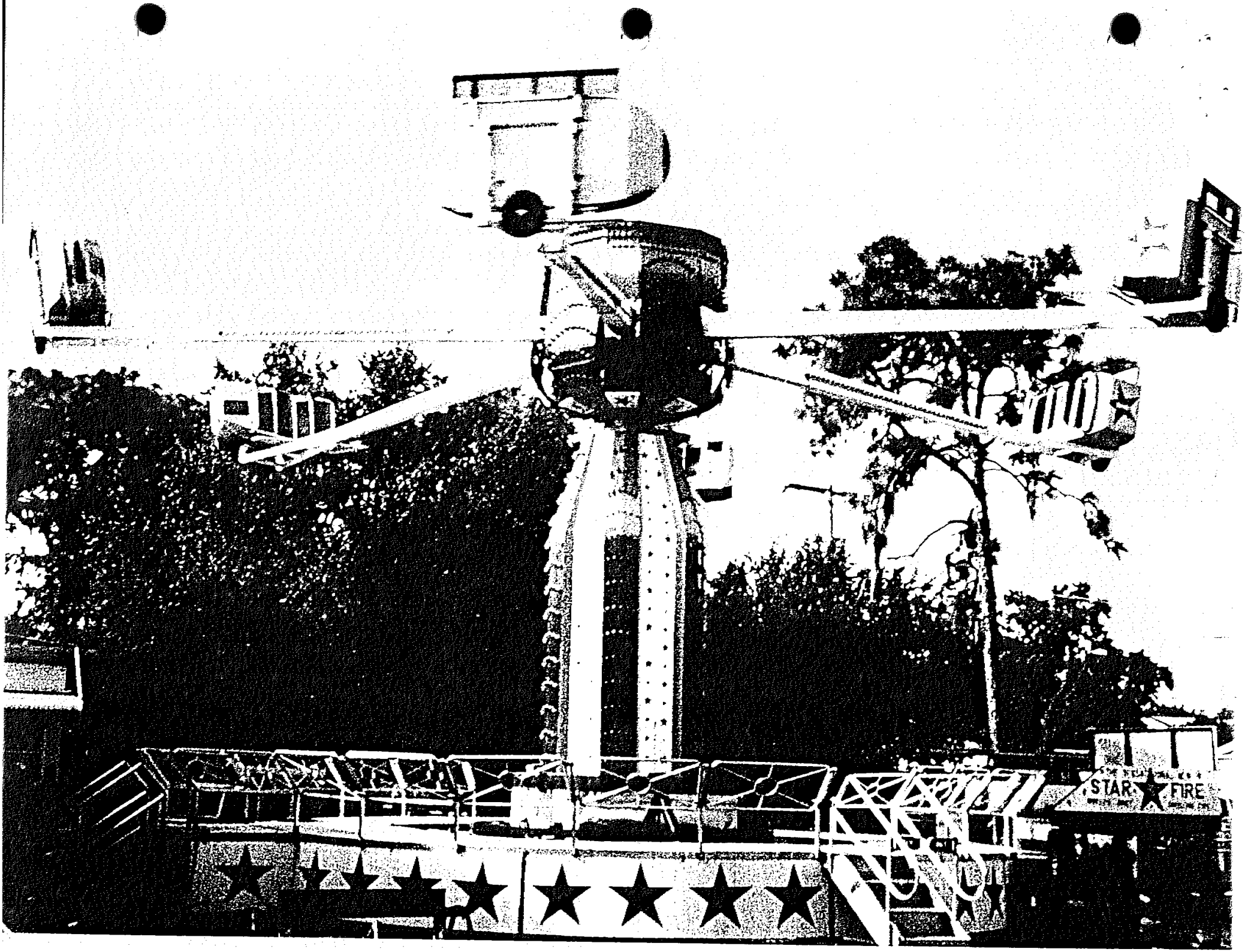
Critical, load bearing components of the ride have been identified and analyzed for maximum stress combinations under operational load conditions. In all cases, the calculated stresses under conservative load assumptions are less than the calculated allowable stresses. The details of the analysis are contained in the calculations in Appendix I. A list of the components considered is as follows:

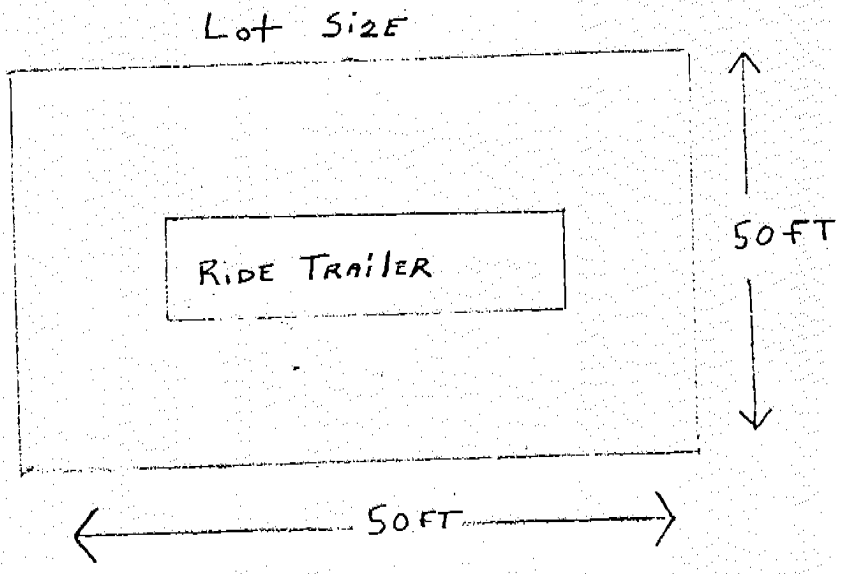
a. Cars: Support brackets, bolted and pin connections
b. Cradles: Structure, pin connections
c. Sweeps: Structure, pin connections, pivot pin
d. Push Arms: Structure, pin connections
e. Crown: Structure
f. Zoomer Pole Top Plate: Structure, pin connections
g. Zoomer Pole: Structure, pin connections
h. Center Pole: Structure, flange connections

## 6. STABILITY

The stability of the Star Fire amusement ride has been examined under operational and wind loads. The stability analyses for operational and wind loading are conservatively based on the trailer wheel base and neglect the outboard stabilizers.

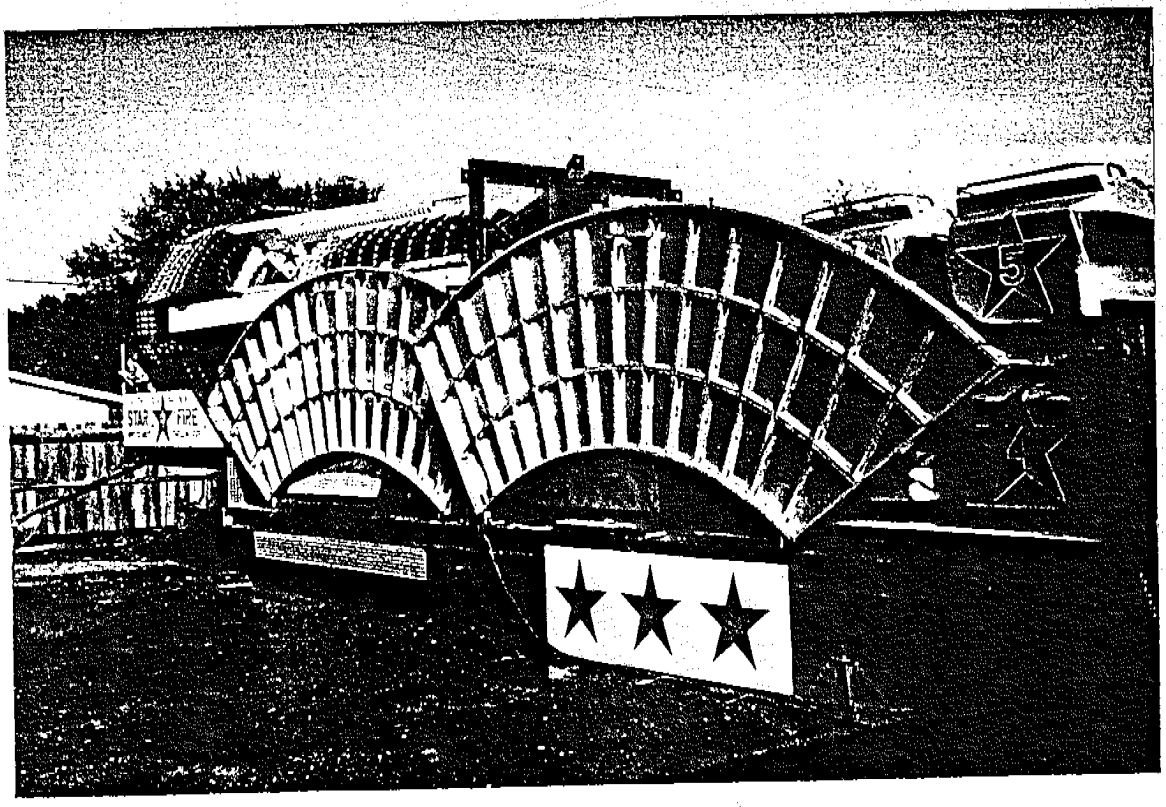
It has been shown that the ride is stable under the worst possible case of passenger imbalance loading. When combined with operational imbalance loading, the ride has been shown to be stable at wind velocities up to 150 mph.


STAR
FIRE

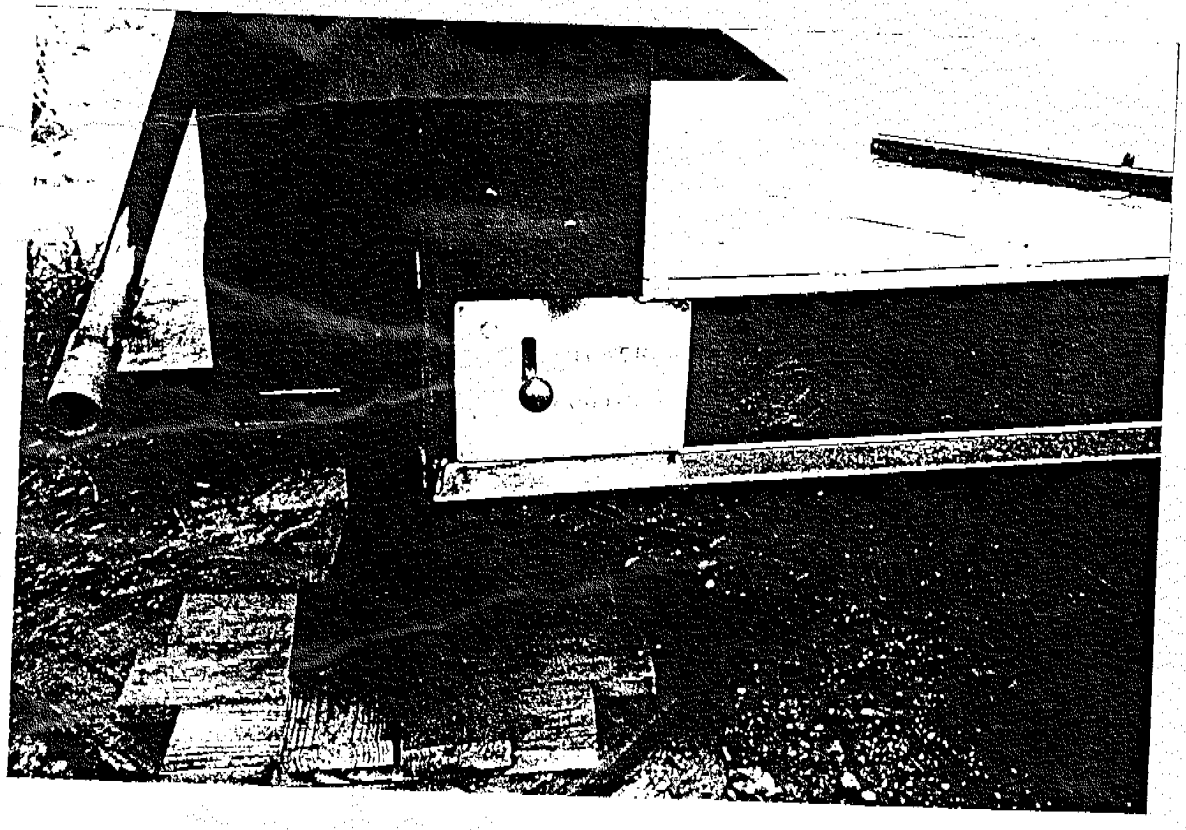



SECURE A 50 X 50 SECTION, PULLING RIDE INTO CENTER WITH REAR OF TRAILER FACING MIDWAY.

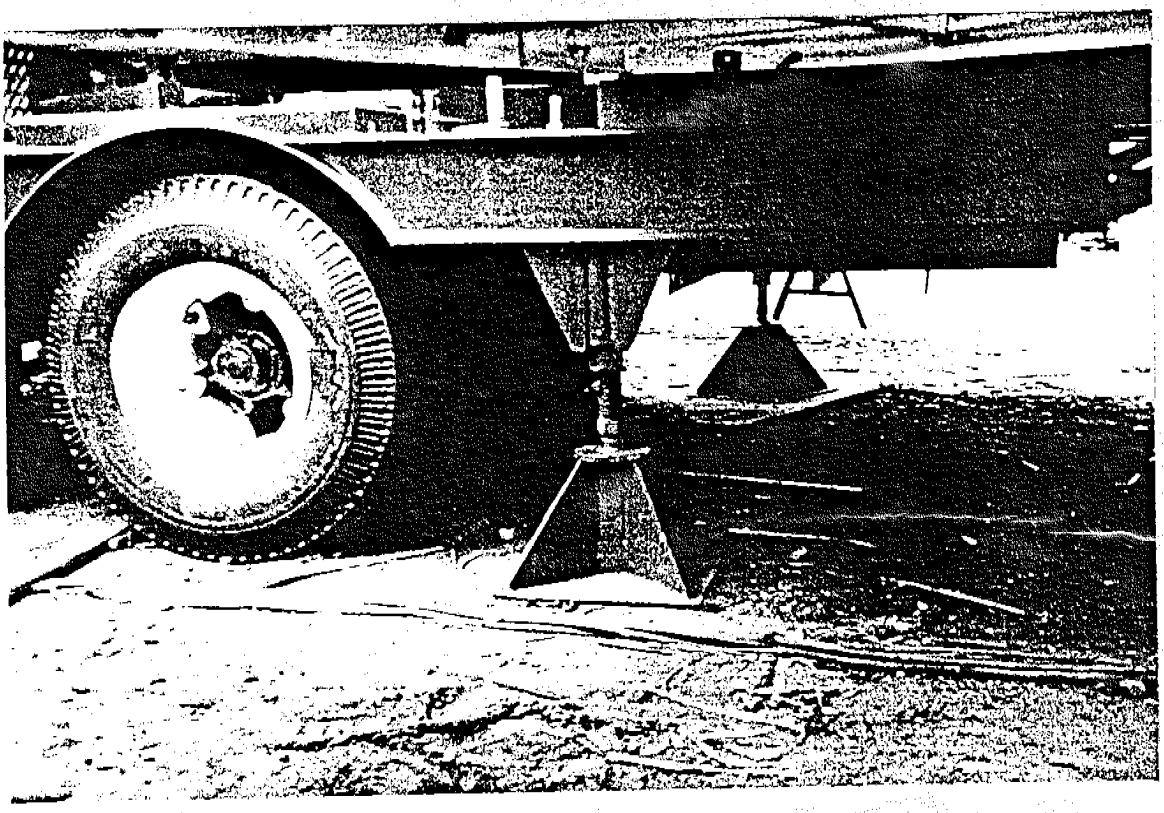
CHECK SIDE TO SIDE LEVEL OF TRAILER ( REAR ) & PLACE BLOCKING UNDER TIRES TO BRING TO APPROX. LEVEL IF NEEDED.



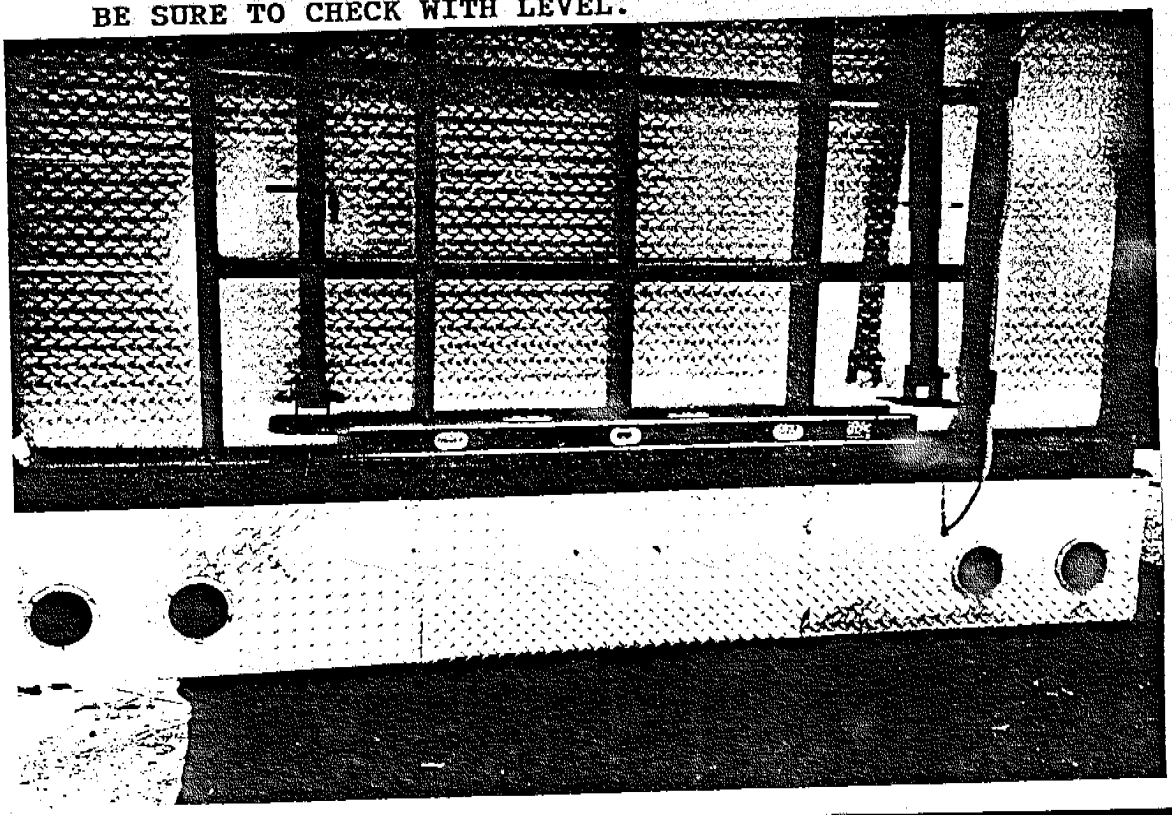
DISCONNECT TRACTOR AND RAISE / LOWER FRONT ELEVATOR JACKS UNTIL FRONT OF TRAILER APPROX. 4 TO 6 INCHES BELOW LEVEL.



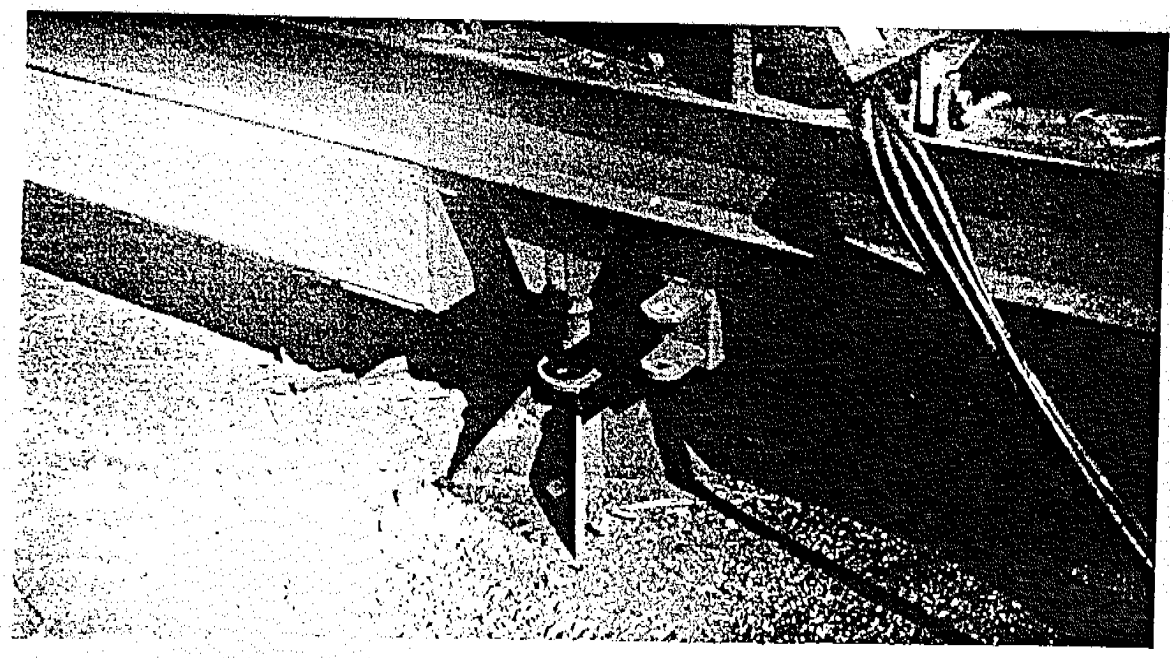
INSTALL LEVELING STANDS AT REAR OF RIDE AND LOWER SCREWS UNTIL SNUG.(IF NOT LEVEL SIDEWAYS,WRENCH LEVEL.)

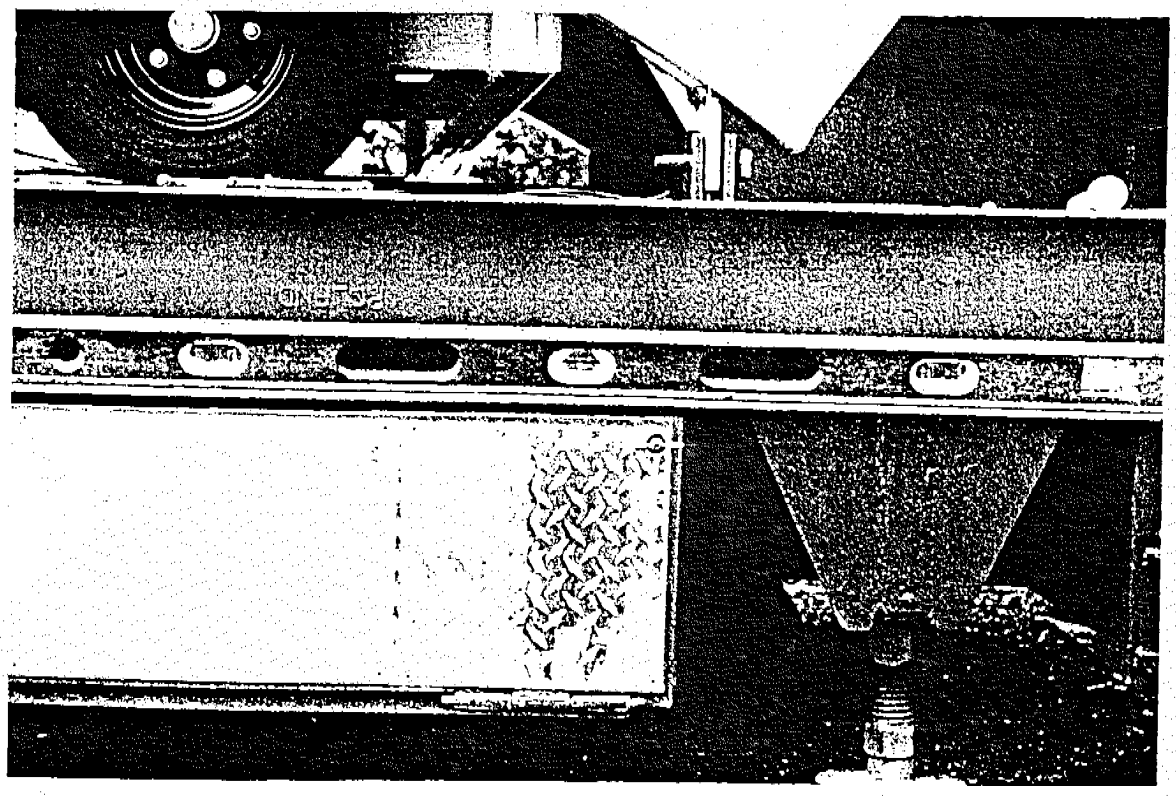


BE SURE TO CHECK WITH LEVEL.



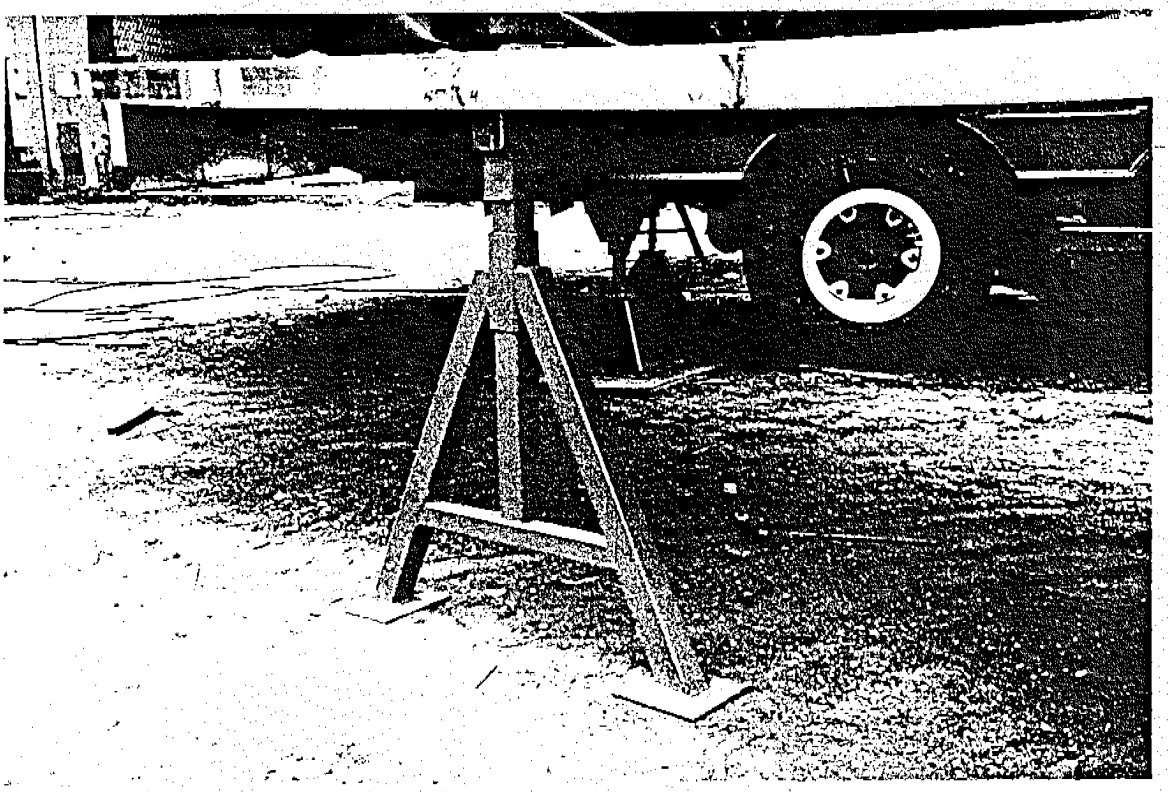
RAISE FRONT OF TRAILER UNTIL LEVEL & PLACE CENTER STANDS UNDER RIDE.LOWER SCREWS UNTIL SNUG.





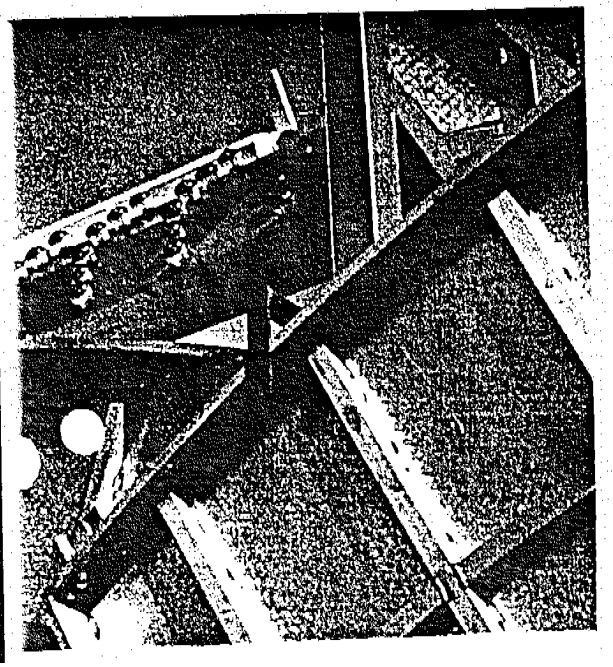
REMOVE PLATFORM SUPPORTS FROM STORAGE AND INSTALL

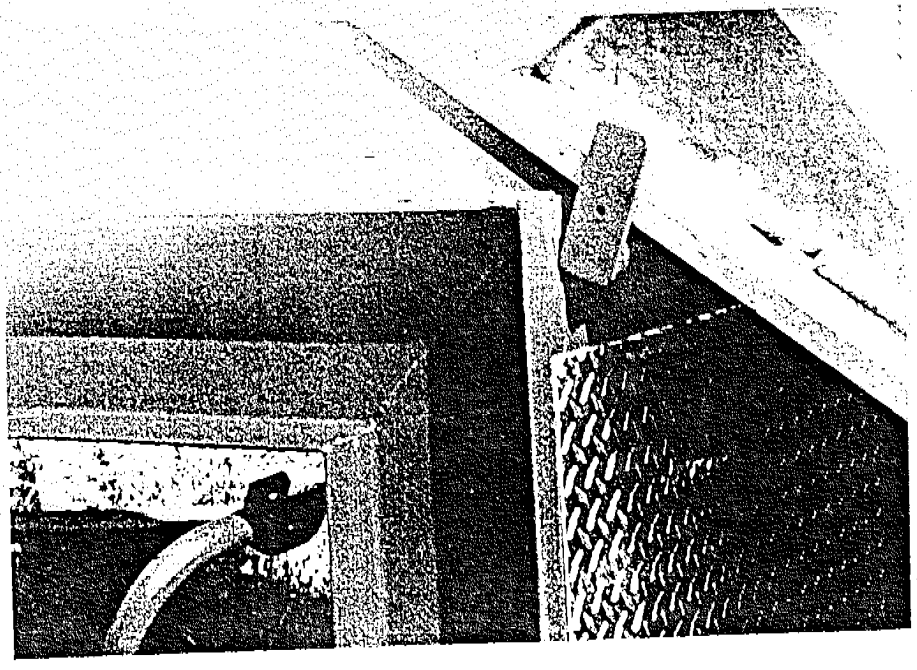
AS SHOWN.



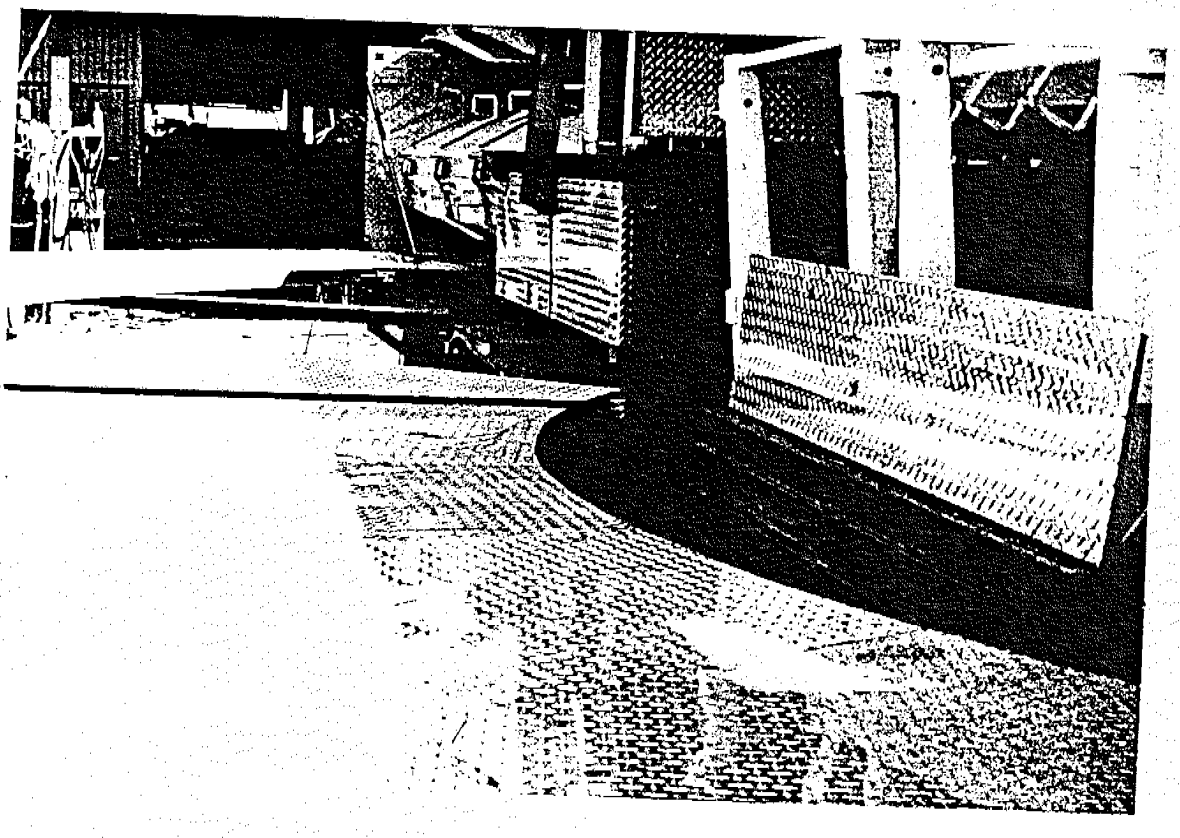
DISCONNECT PLATFORM LATCHES AND SWING PLATFORMS DOWN.

( BACK PLATFORM MUST BE LOWERED FIRST.)

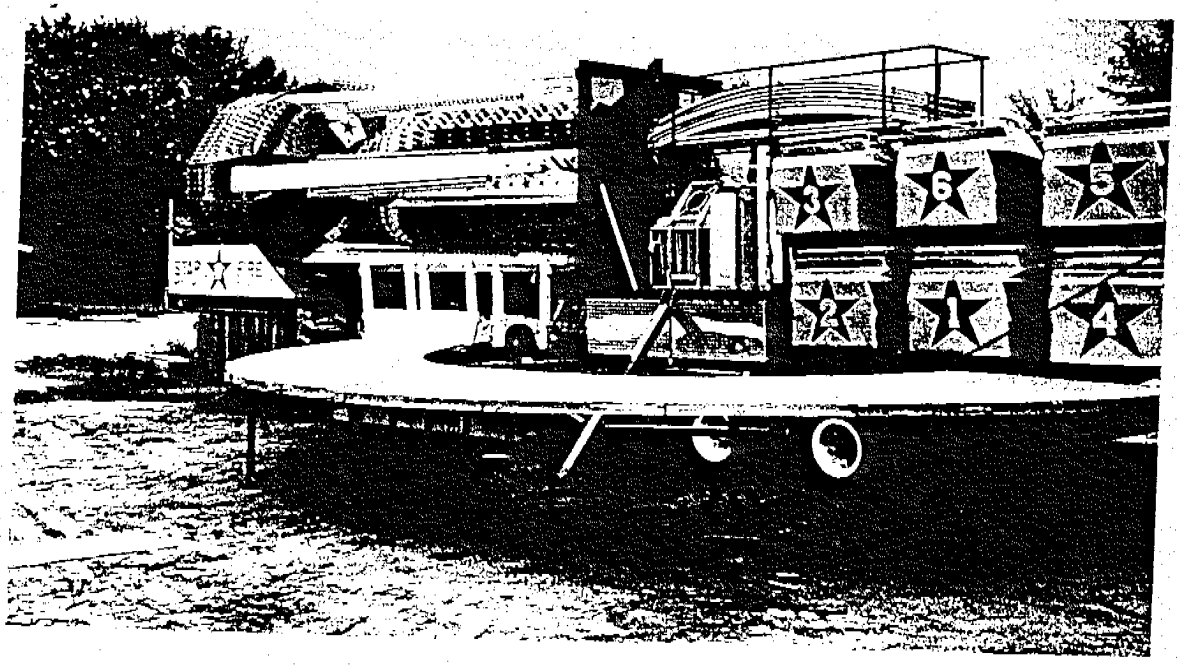




REMOVE PLATFORM HINGE PINS AND PLACE PLATFORMS IN POSITION AND SECURE WITH 1/2 INCH PINS.



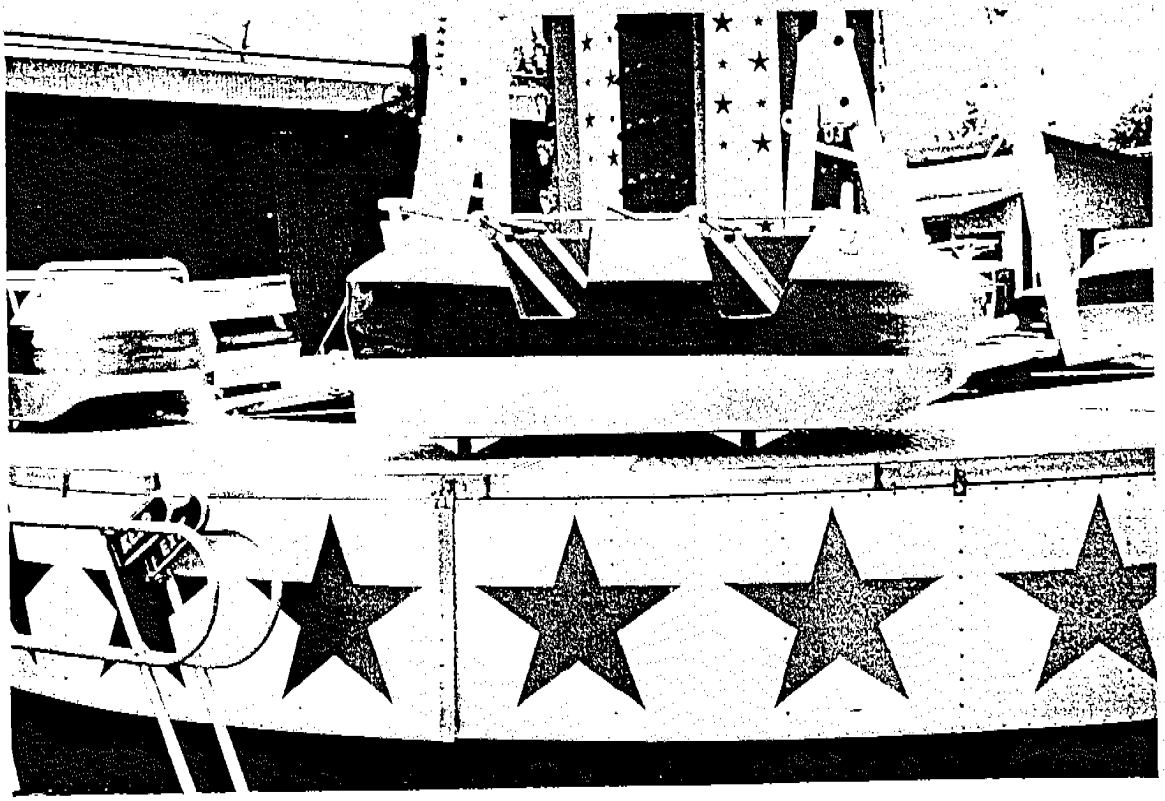
RAISE / LOWER PLATFORM SUPPORTS UNTIL PLATFORMS ARE LEVEL.



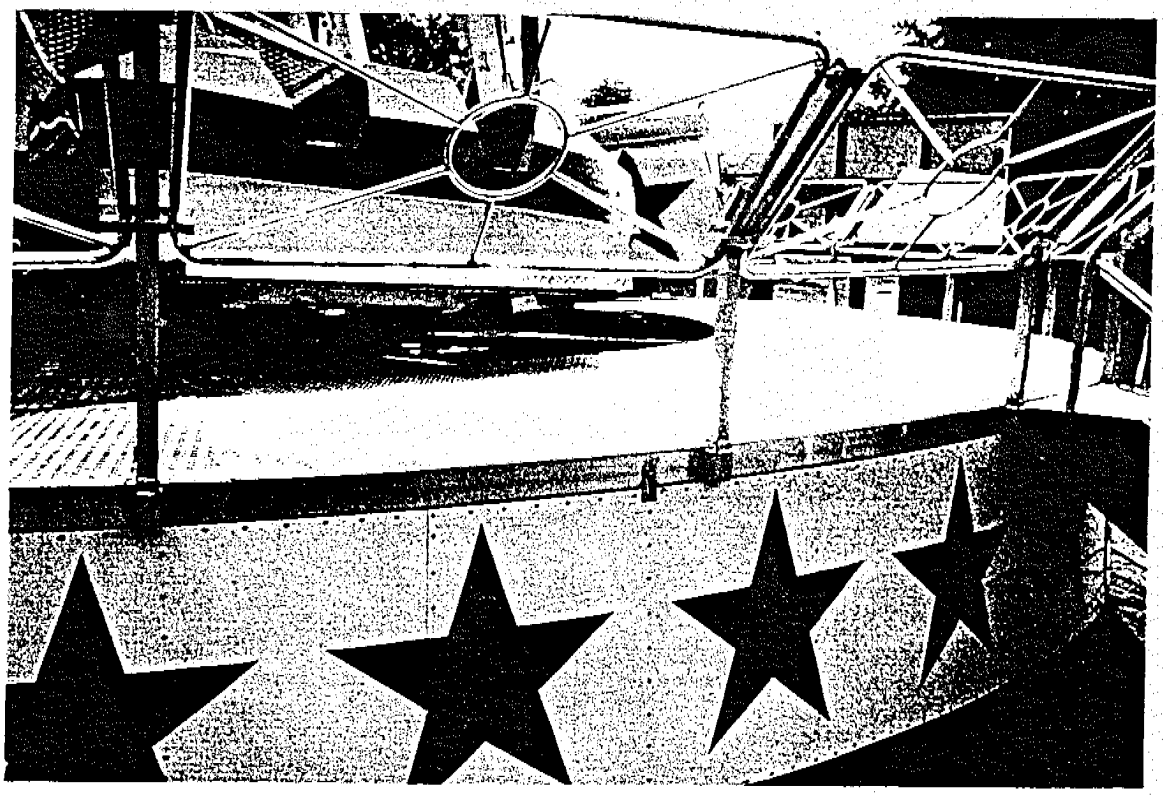
REMOVE CARS FROM RACK AND PLACE AROUND PLATFORMS.

PLACE RACKS UNDER PLATFORMS.

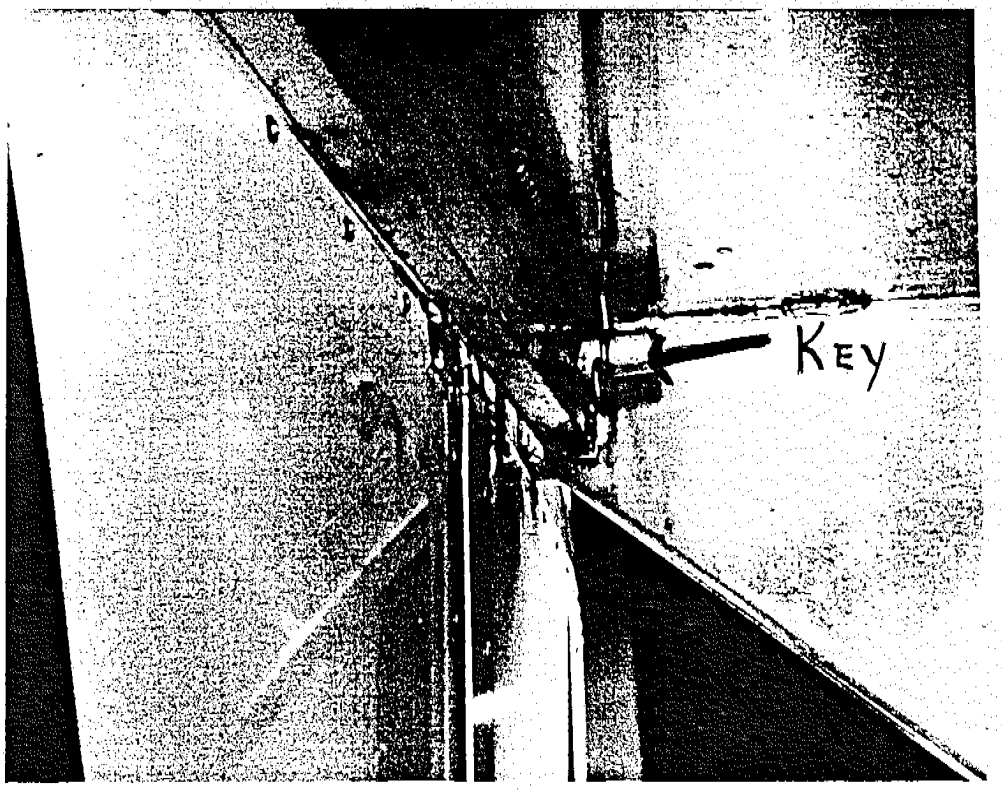
LOWER STEP PLATFORM.

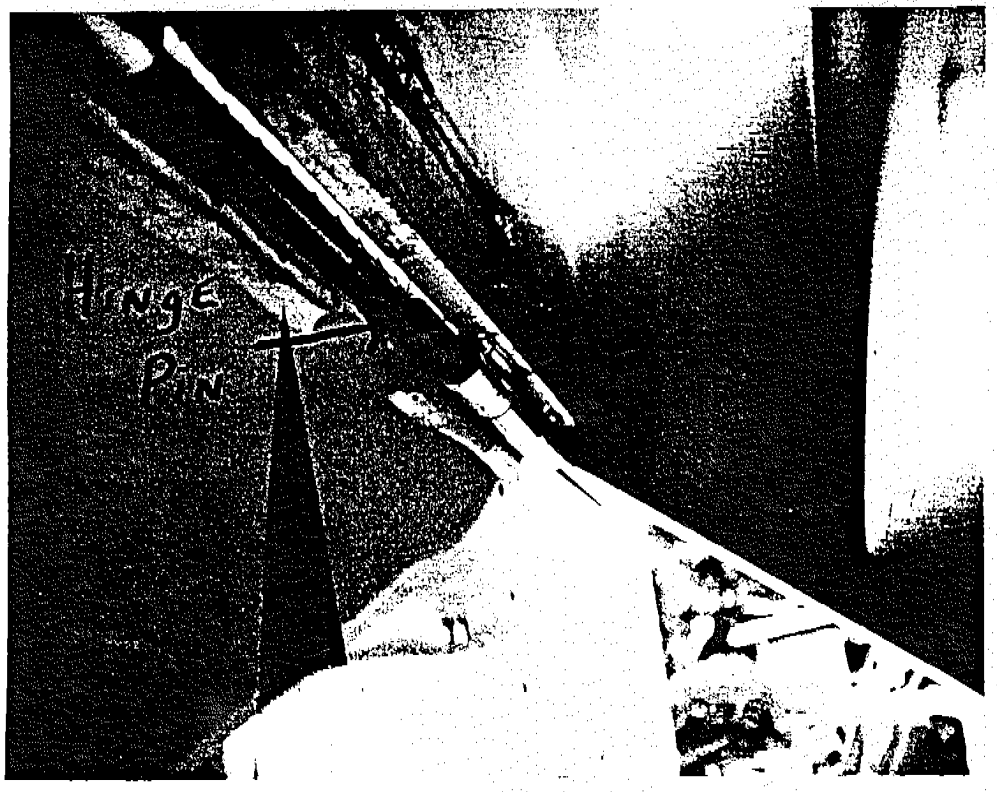


INSTALL PLATFORM SCENERY AND FENCING FROM FRONT OF TRAILER TO REAR. INSTALL STEPS. PIN AND KEY EVERYTHING.

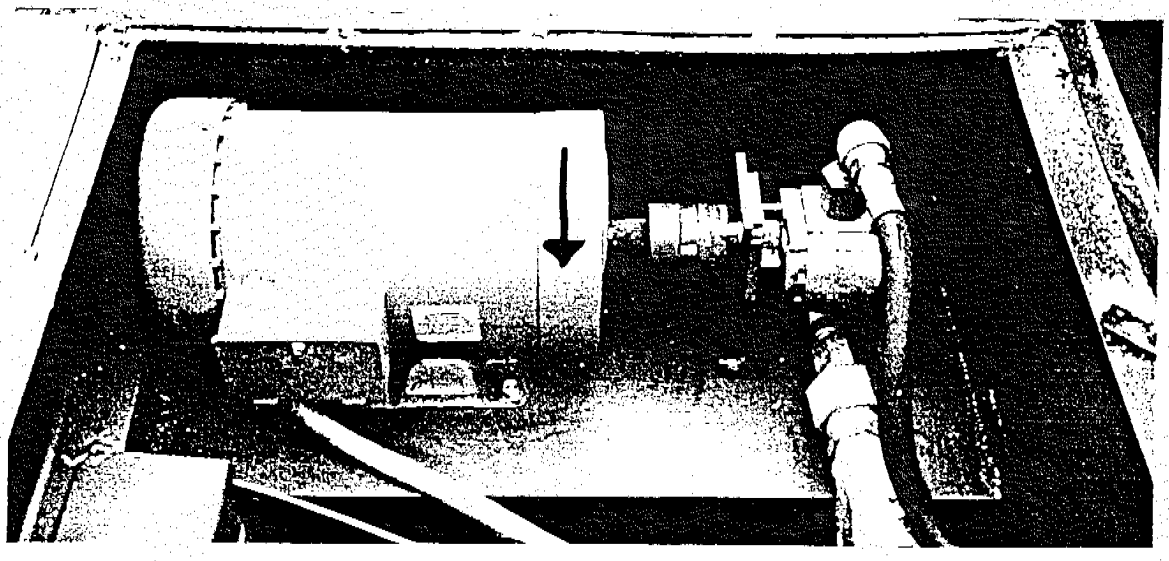


INSTALL STEPS . BE SURE TO PIN AND KEY EVERYTHING.



UNCOIL LEADLINE AND CONNECT TO MINIMUM 200 AMP. 3 PHASE CIRCUIT. TURN ON MAIN BREAKER ,CIRCULATOR PUMP WILL START. MOMENTARILY TURN SET UP PUMP ON AND OFF TO CHECK CORRECT MOTOR ROTATION. INTERCHANGE ANY 2 HOT LEADS IF INCORRECT.( SEE ARROW FOR CORRECT ROTATION) ALL MOTORS ARE NOW CORRECTLY PHASED.



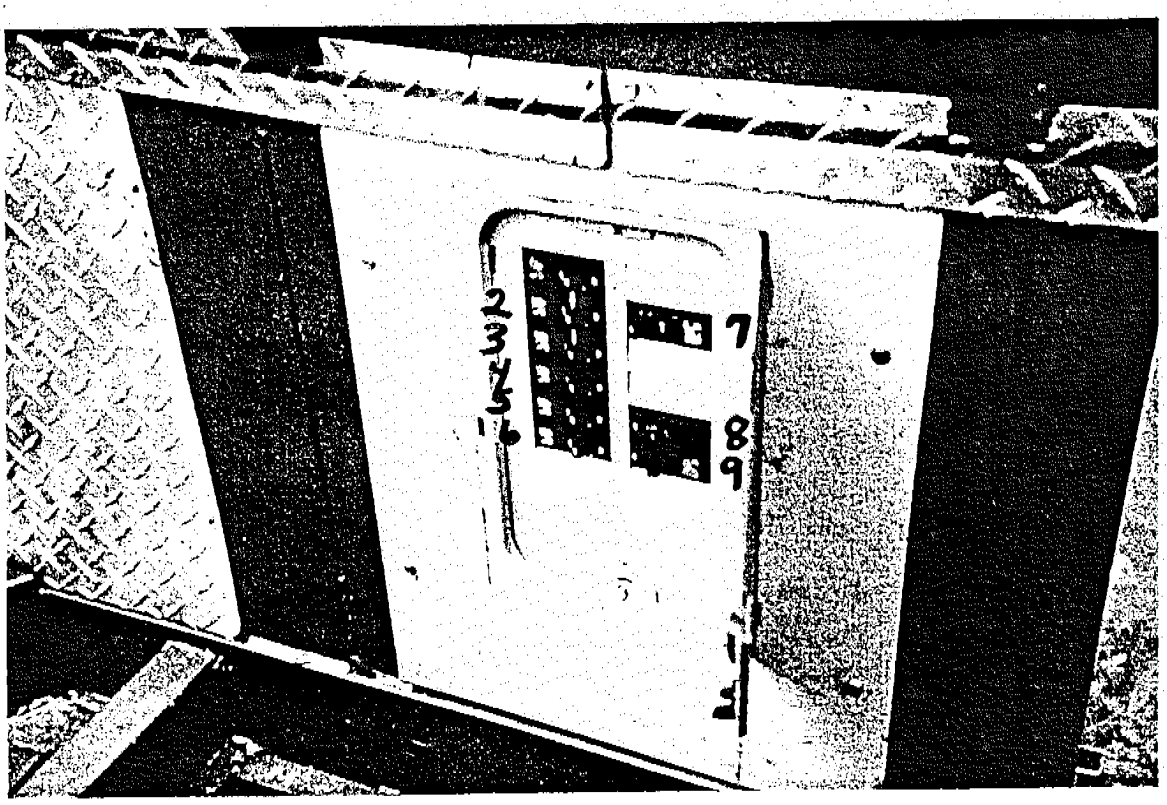
TURN ON SET UP MOTOR AT CIRCUIT BREAKER.

1, 2, 3 } SET UP

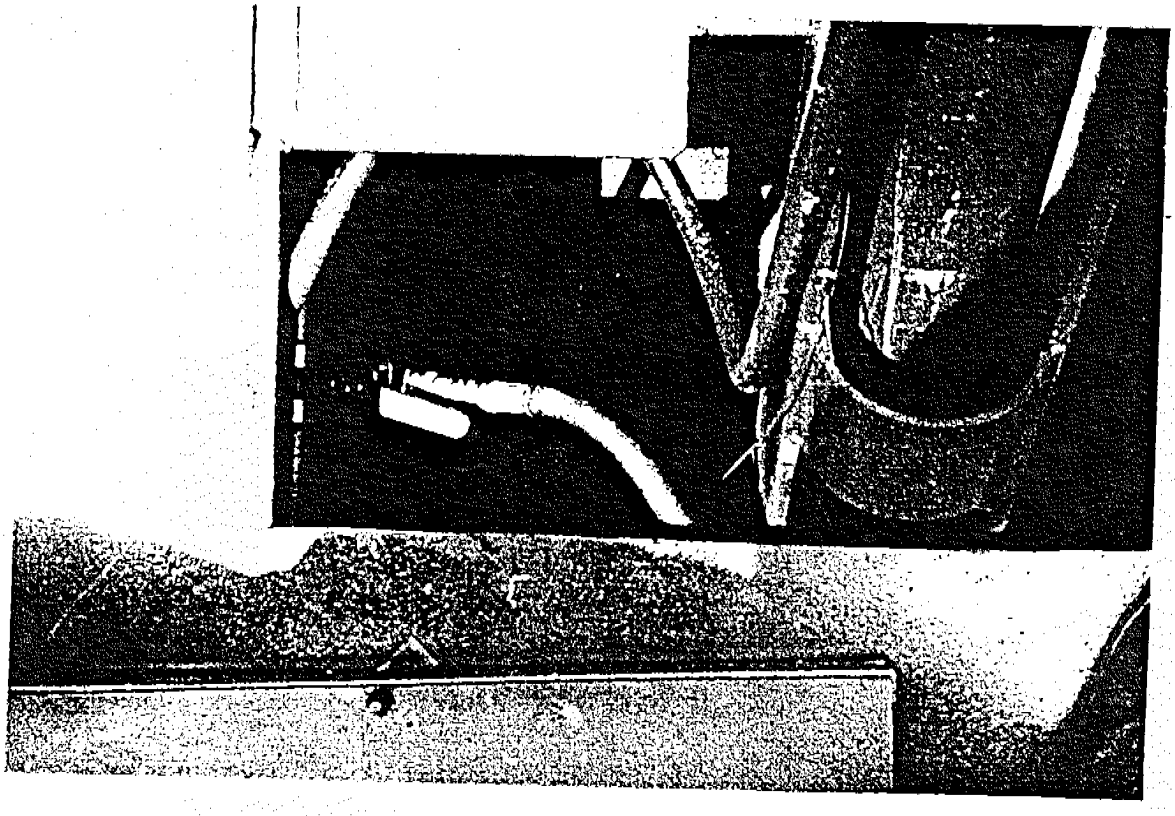
4, 5, 6 } TOWER LIGHTS

7 CONTROL VOLTAGE

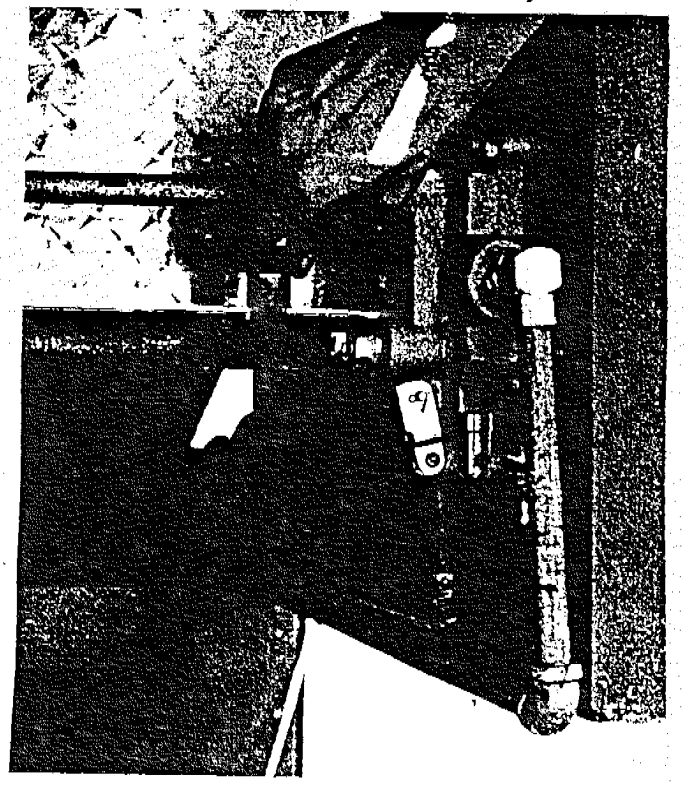
8, 9 } crown lights



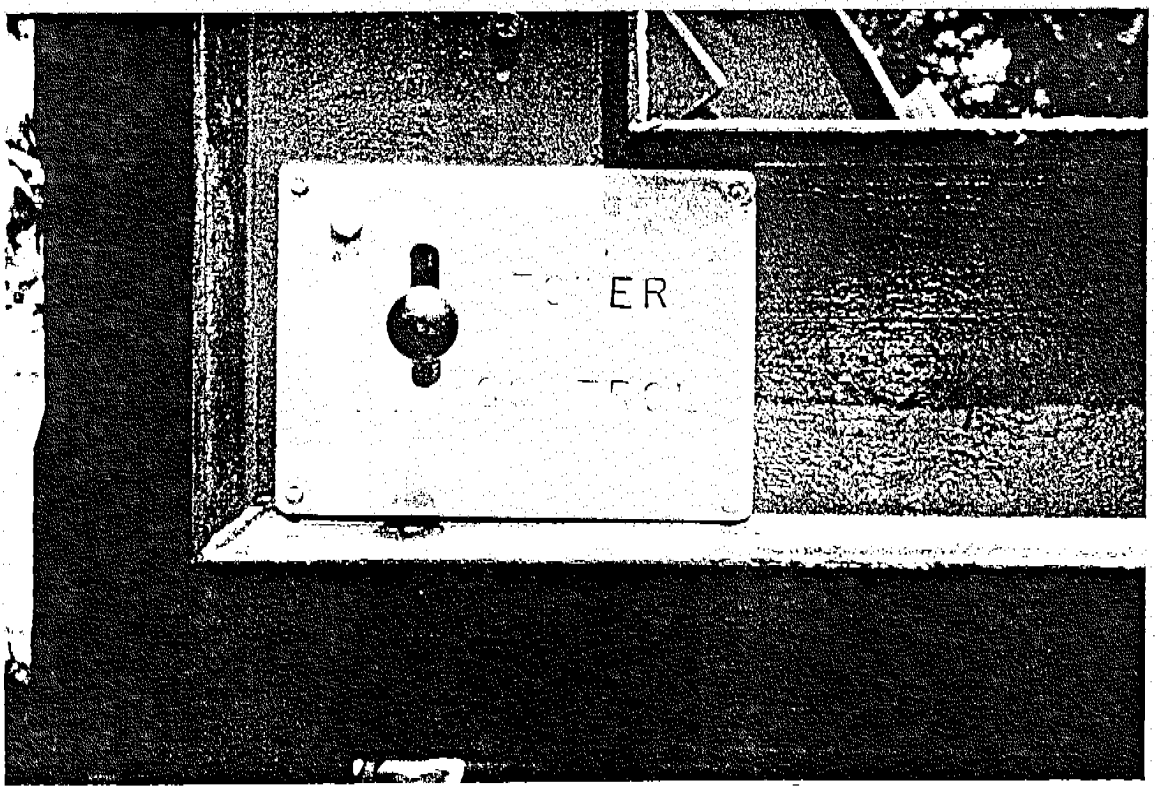
CHECK TO INSURE PETCOCK ON FRONT CYLINDER IS FULLY OPEN & TOWER IS FREE AND CLEAR OF ALL OBSTRUCTIONS.



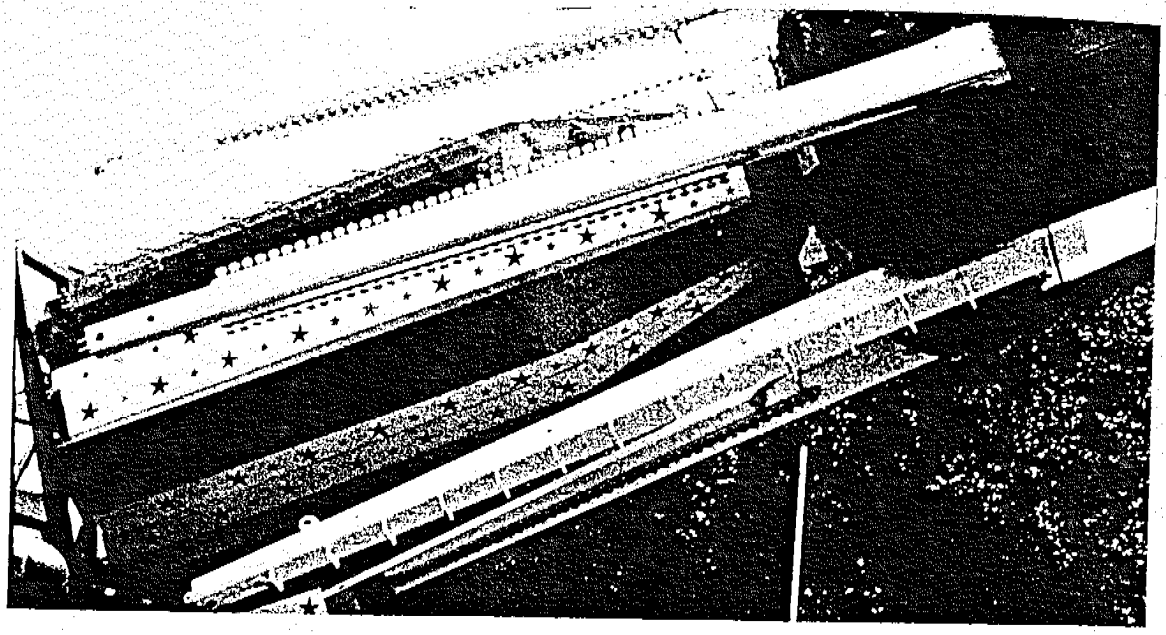
( CLOSE FLOW CONTROL FULLY FOR SAFETY.)



PROCEED THEN TO BEGIN RAISING TOWER BY LIFTING TOWER CONTROL LEVER.



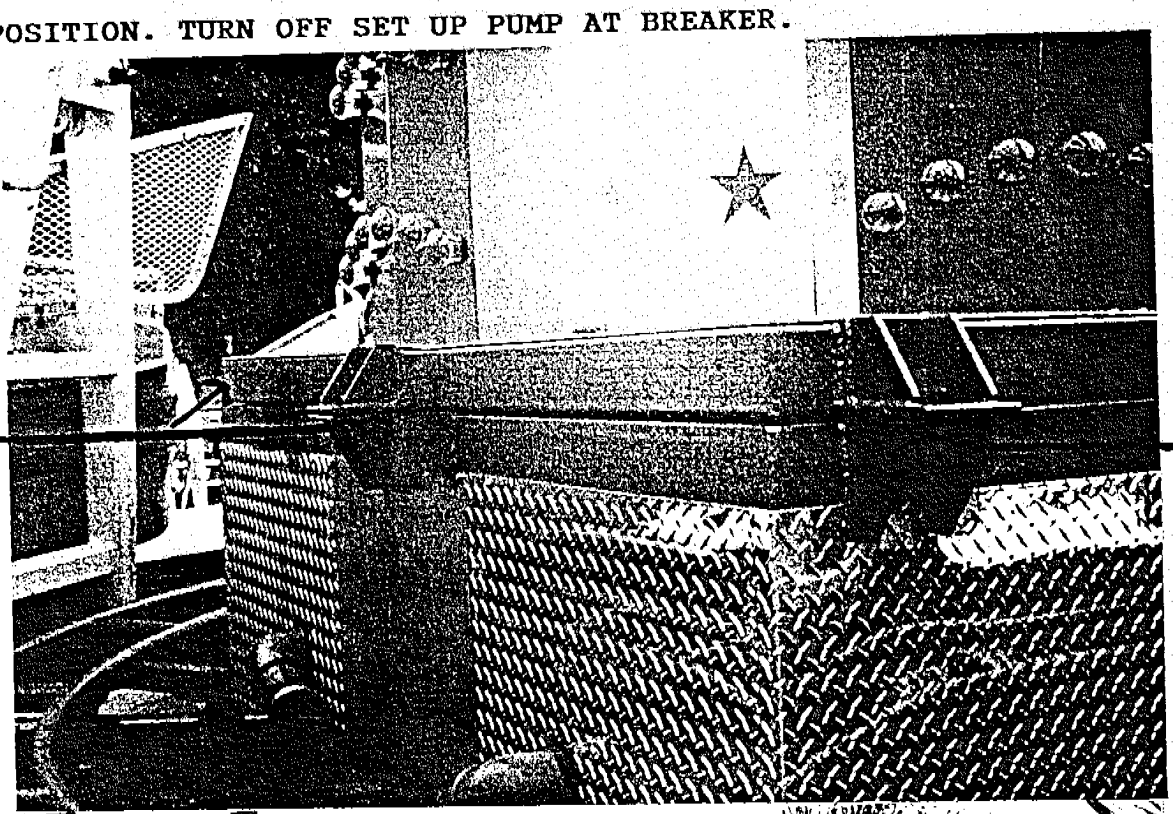
WHEN FRONT CYLINDER IS FULLY EXTENDED, RELEASE LEVER AND CLOSE PETCOCK COMPLETELY.

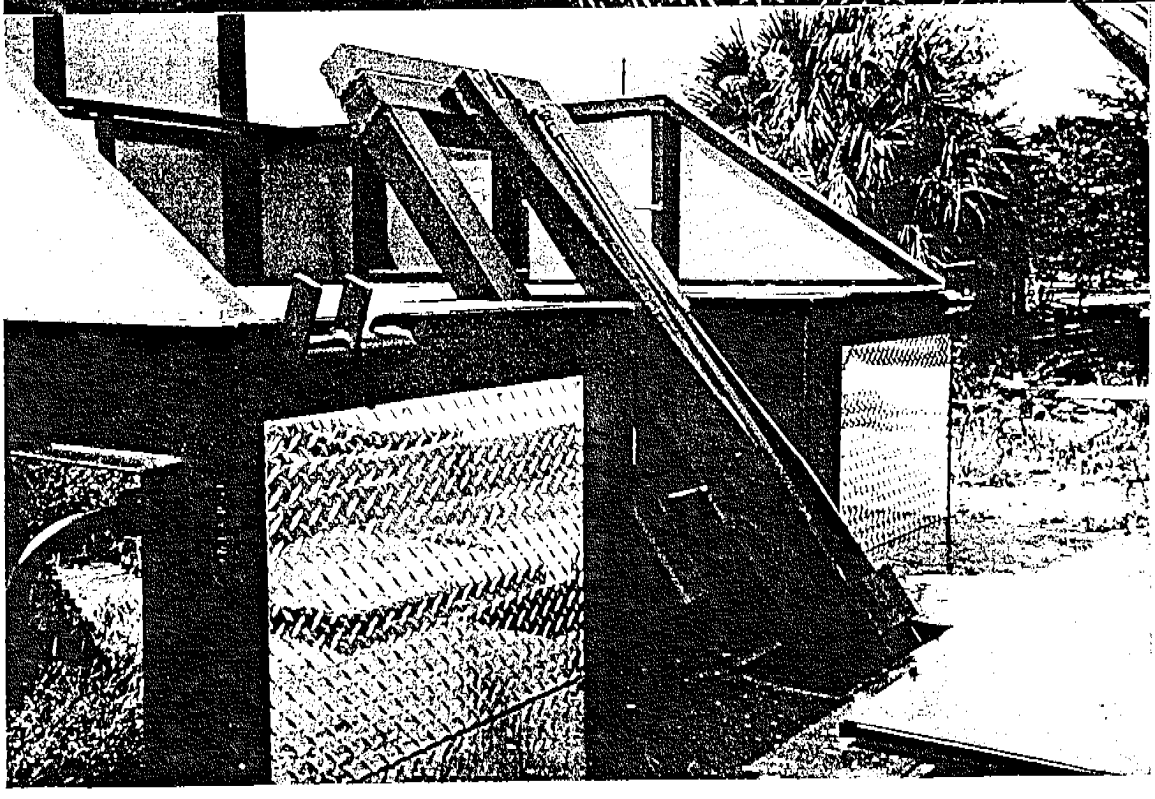


LIFT TOWER CONTROL LEVER AND COMPLETE RAISING.

TURN OFF SET UP MOTOR POWER.

BOLT TOWER TO BASE. WHEN TOWER BOLTED, OPEN PETCOCK AT BOTTOM OF FRONT CYLINDER AND DEPRESS LEVER UNTIL CYLINDER FULLY RETRACTED. THEN PROCEED TO LAY CYLINDER INTO OPERATING POSITION. TURN OFF SET UP PUMP AT BREAKER.

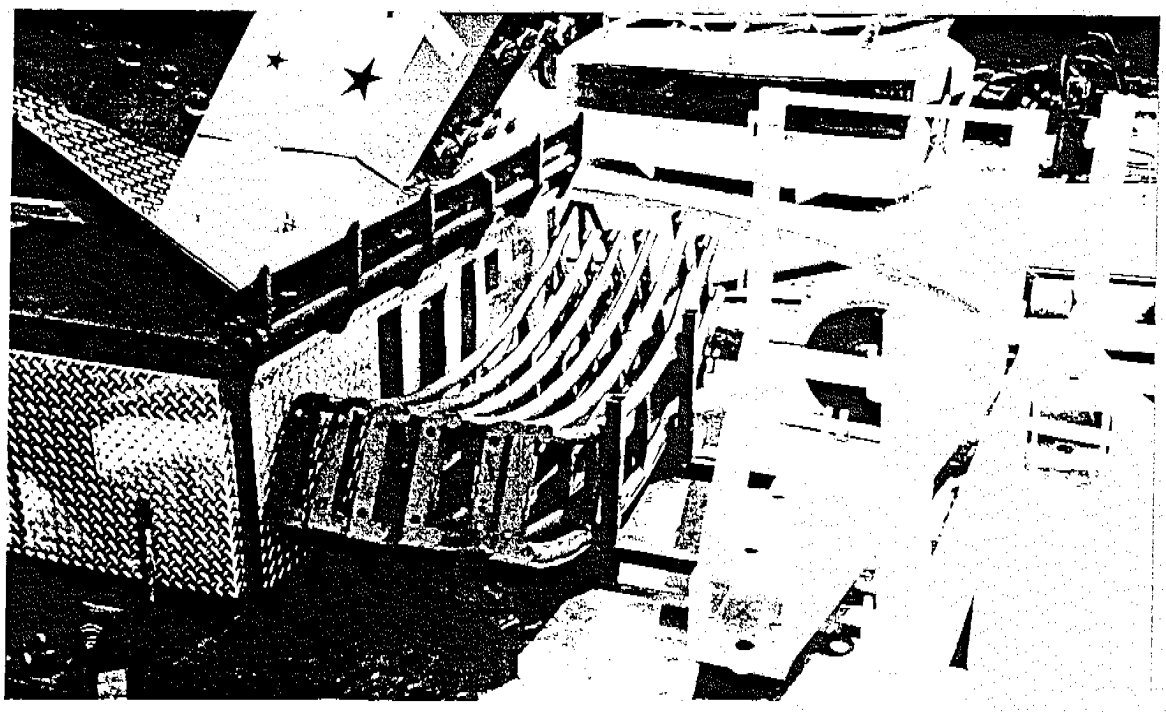


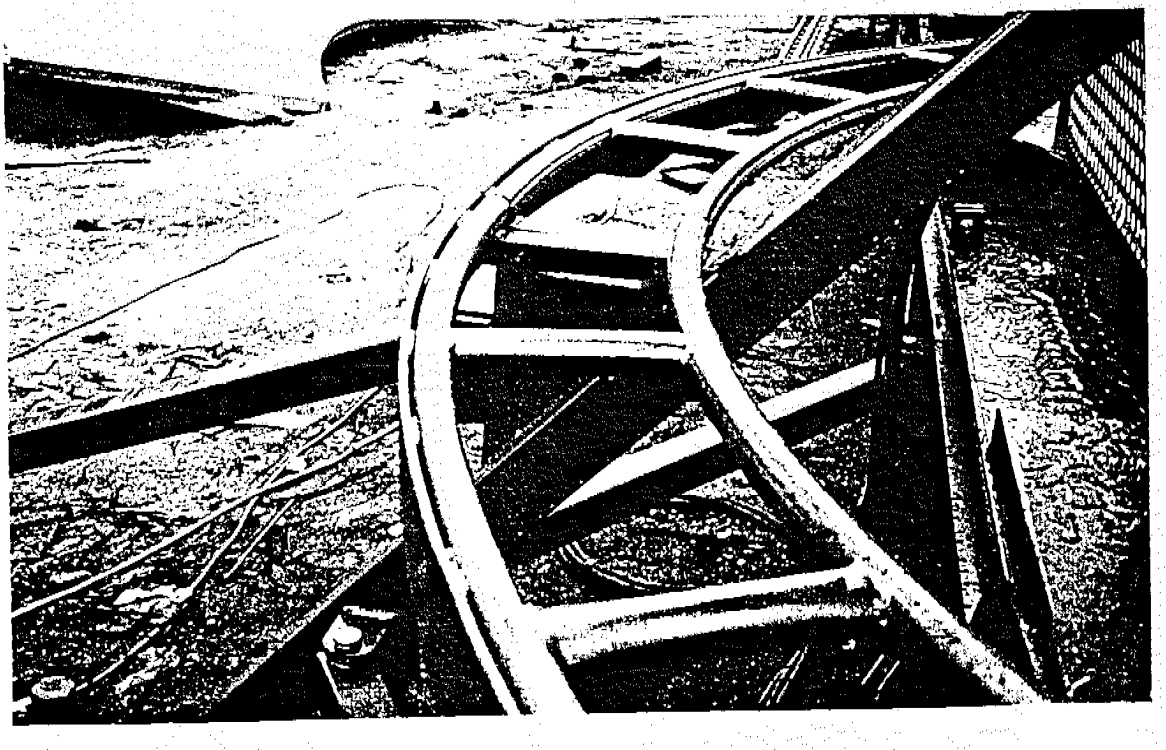



REMOVE TRACK FROM STORAGE AND INSTALL AROUND BASE.

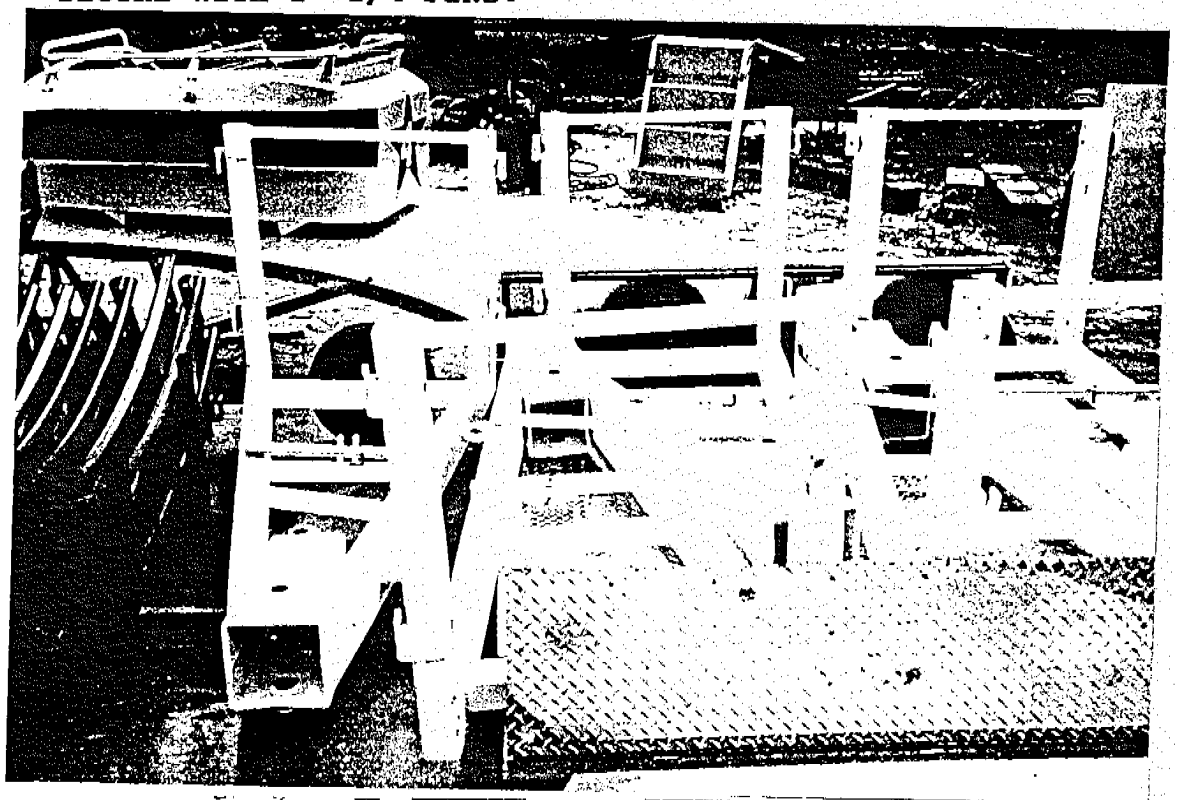
( ALL SECTIONS ARE NUMBERED.)

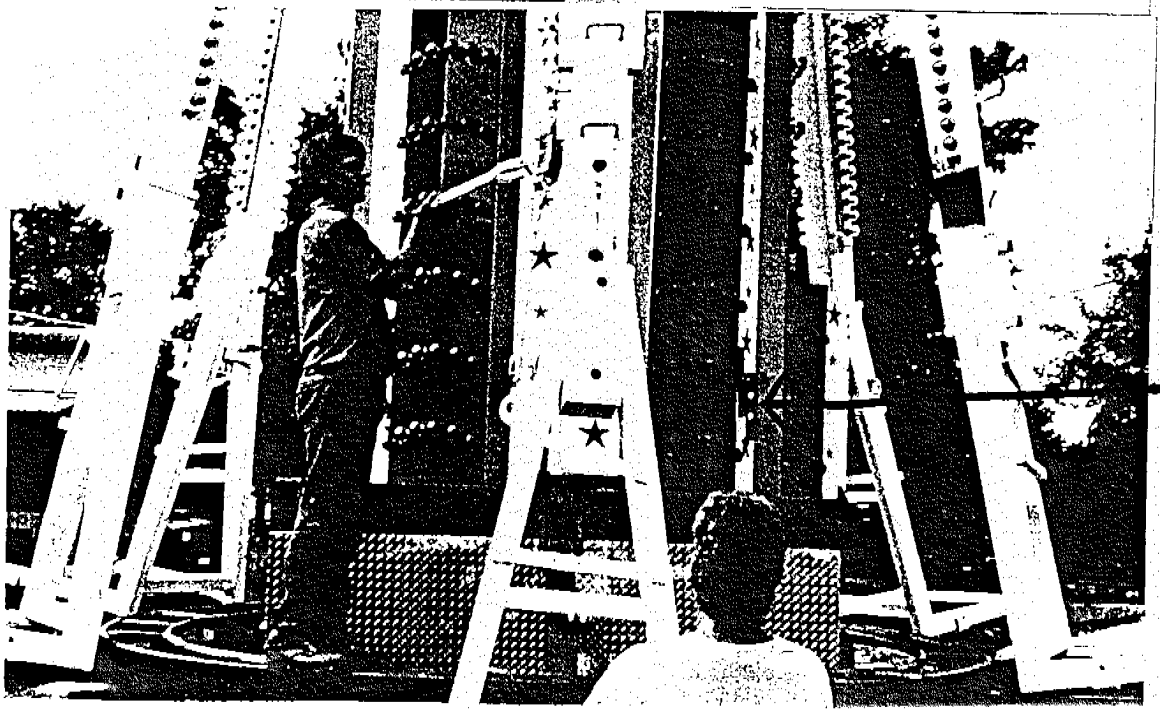
PIN TRACK SECURELY.





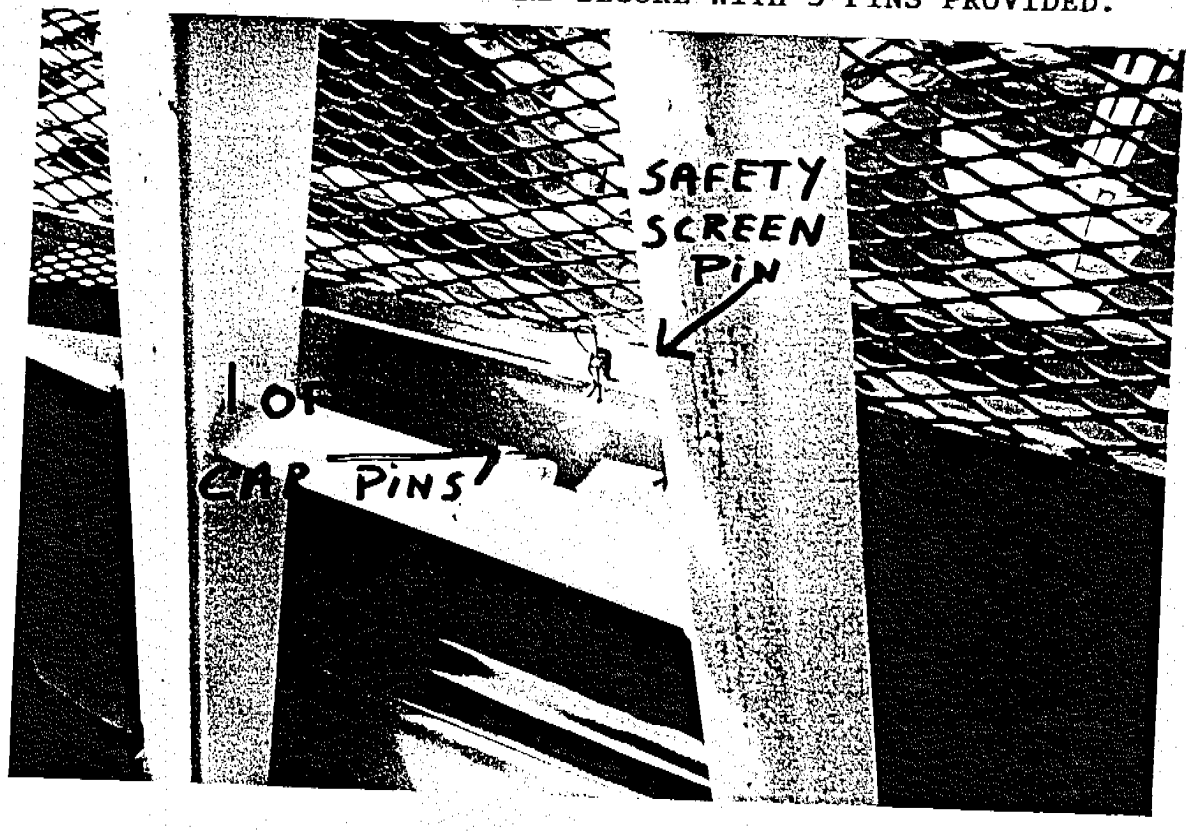
DISCONNECT SWEEPS LOCKS AND PULL SWEEPS OUT FROM TOWER. REMOVE WISHBONES FROM STORAGE AND USING CABLE HOIST, IN STALL ON END OF SWEEPS.(INSURE NUMBERS CORRESPOND) SECURE WITH 1 1/4 PINS.



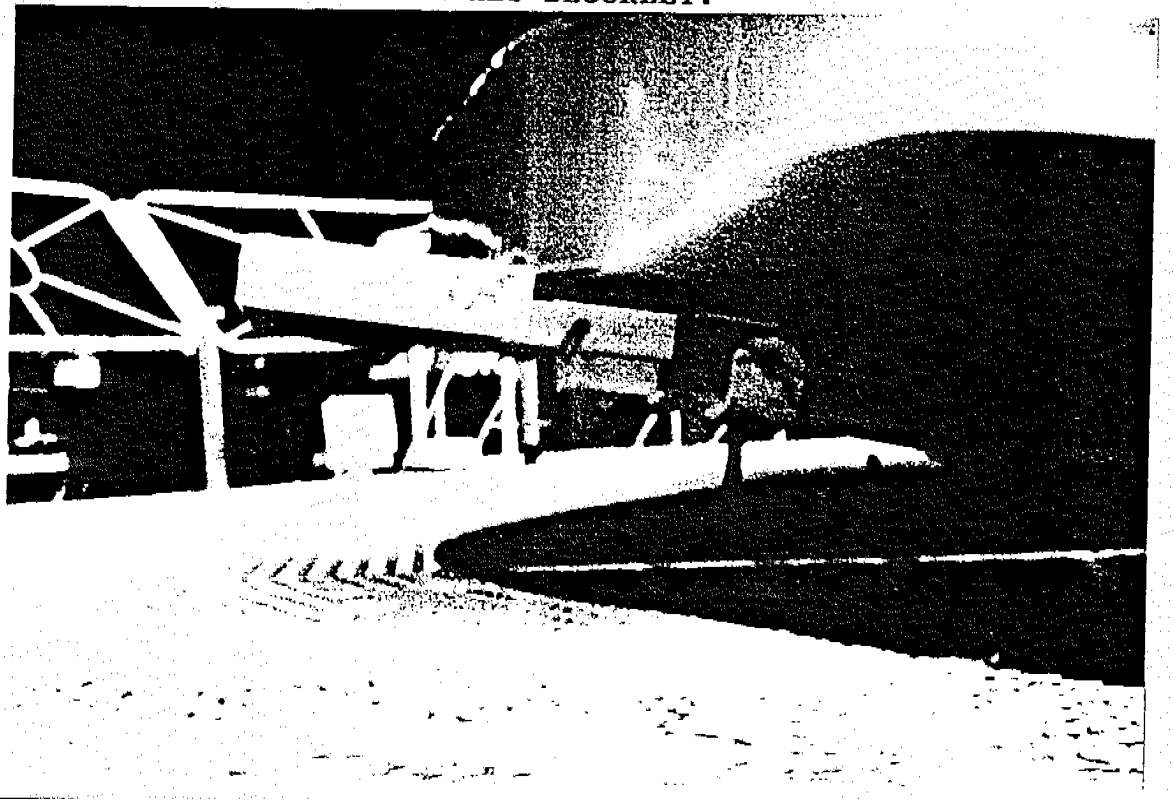


Sweep Locks

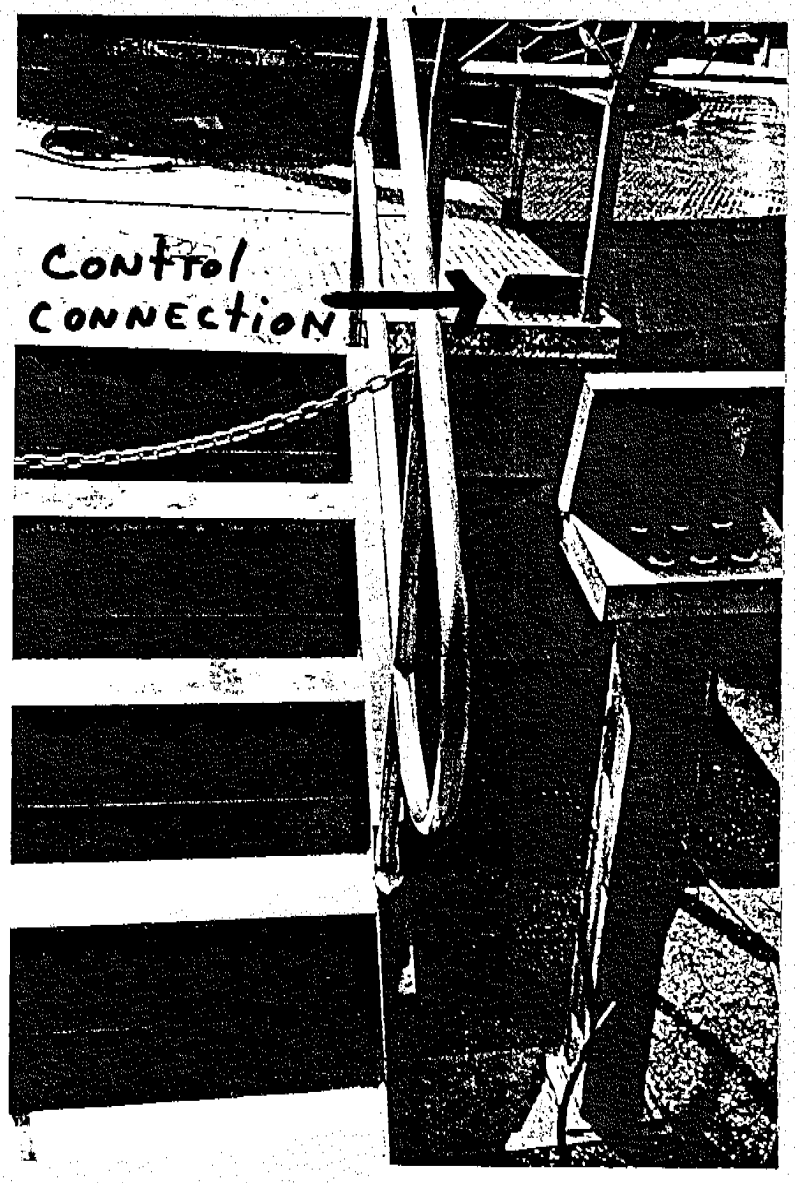
SET CARS ON WISHBONES AND SECURE WITH 5 PINS PROVIDED.




INSTALL FOOT BOARDS & SAFETY SCREENS ON CORRESPONDING NUMBERED CARS. PIN & KEY SECURELY.



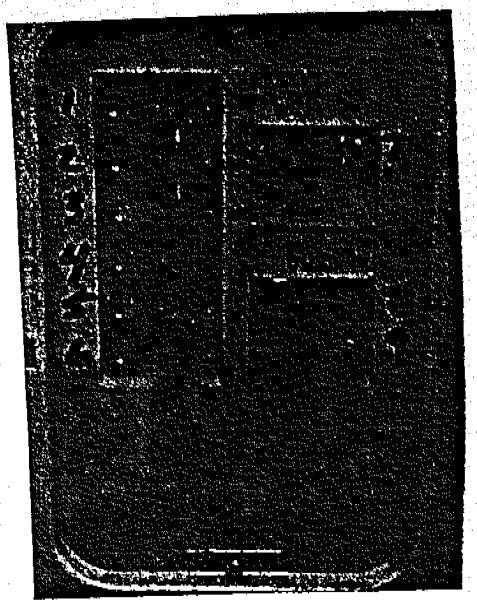
INSTALL CONTROL STATION AT FOOT OF ENTRANCE AND CONNECT TO SOCKET AT RIGHT REAR OF STEP PLATFORM.



TURN ON CONTROL VOLTAGE AND LIGHTING CIRCUITS.

CIRCUIT BREAKER LAYOUT

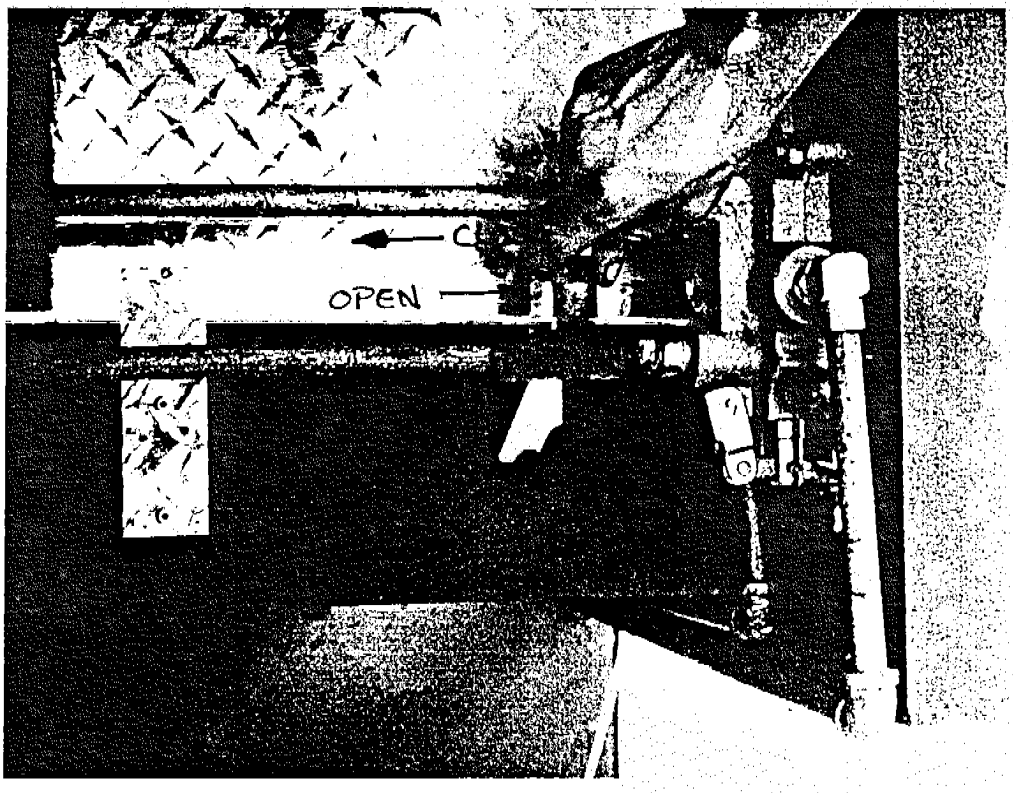
1)
2) SET UP
3)
4) TOWER 1
5) TOWER 2
6) TOWER 3
7) NOT USED
8) CONTROL VOLTAGE
9) NOT USED
10)NOT USED
11) CROWN & SWEEP(A)
12) CROWN & SWEEP(B)



## TEAR DOWN

REVERSE SET UP PROCEDURE WITH THE FOLLOWING EXCEPTION.

*** CLOSE FLOW CONTROL VALVE COMPLETELY. THEN TURN NO MORE THAN 2 1/2 TURNS OPEN BEFORE LOWERING TOWER.



# OPERATION INSTUCTIONS

1) ENSURE ALL LAP BARS ARE DOWN & LOCKED.
   CHECK FOR CLEAR PLATFORMS

2) PRESS MAIN START & WAIT 10 SECONDS.

3) PRESS AND HOLD SPEED UP, APPROX. 10 SECONDS OR UNTIL FULL THROTTLE INDICATOR ( RED ) LIGHTS.

4) WHEN LIFT APPROVE INDICATOR ( GREEN )LIGHTS, ROTATE LIFT SWITCH TO ON POSITION, PUMP WILL START.

5) AFTER 8 TO 10 SECONDS RIDE WILL BEGIN TO LIFT & ALTERNATE.

## TO STOP RIDE

6) ROTATE LIFT TO OFF POSITION, WAIT 10 SECONDS FOR RIDE TO LEVEL.

7) PRESS AND HOLD SPEED DOWN APPROX. 10 SECONDS.

8) PRESS AND HOLD BRAKE UNTIL RIDE SLOWS TO WITHIN 3 FT OF TRACK RELEASE BRAKE.

9) WHEN WHEELS ON TRACK, PRESS BRAKE UNTIL RIDE COMES TO A COMPLETE STOP.

10) PRESS PUMP STOP.

*** LIFT WILL NOT OPERATE UNTIL RIDE REACHES CORRECT ROTATION SPEED.

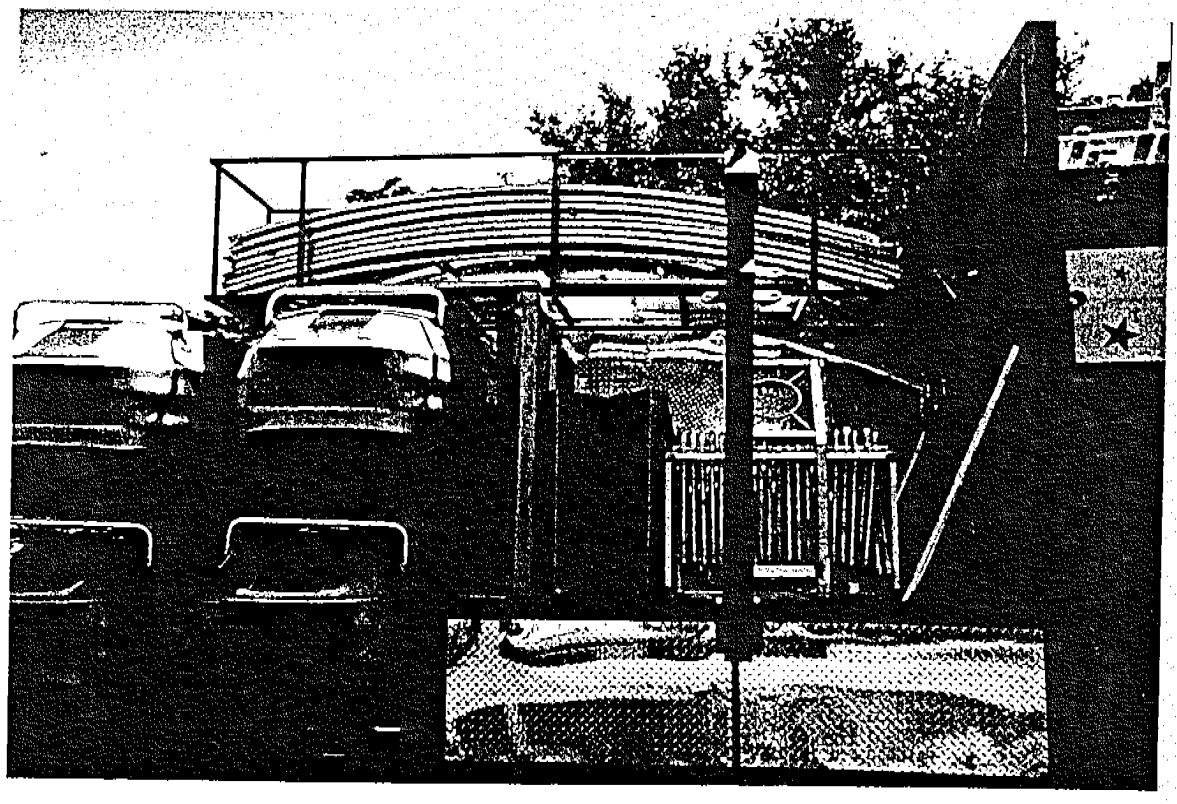
*** IN CASE OF POWER LOSS ,ROTATE LIFT TO OFF POSITION,THROTTLE WILL AUTOMATICALLY RESET TO NEUTRAL.

*** IF LIFT SWITCHED OFF & BACK ON,10SECONDS WILL ELAPSE BEFORE LIFT WILL RESUME.

*** IF THROTTLE IS NOT FULLY OPEN, LIFT WILL NOT OPERATE, IF SPEED IS REDUCED DURING RIDE, LIFT WILL DISENGAGE.

*** DO NOT ATTEMPT TO RESET OR ADJUST LIFT CYCLE, TAMPERING WITH CIRCUITRY WILL VIOD WARRANTY.

# STORAGE FOR TRANSIT



# PREVENTATIVE MAINTENANCE CHECKS AND SERVICES

## DAILY;

1) CHECK ALL PINS & KEYS THROUGH OUT FOR SIGNS OF WEAR AND OR MISSING KEYS.

2)CHECK LIGHTS FOR LOOSE OR BURNT OUT BULBS. ALSO CHECK FOR WATER TRAPPED IN LENSES.

A) IF A LARGE # OF BULBS ARE IN-OPERATIVE ON RIDE, TEST CIRCUIT.

B) IF ON CROWN /SWEEPS, FUSE ACCESS IS ON TOP CENTER OF CROWN

C) IF ON TOWER, FUSE ACCESS IS BEHIND ELECTRICAL ACCESS COVER LOCATED IN FRONT CORNER OF TOWER BASE.

B)&C) NON SERVICEABLE BY RIDE OPERATOR. NOTIFY RIDE SUP.

3) CHECK FOR LOOSE, FRAYED OR BROKEN WIRING THROUGH-OUT.

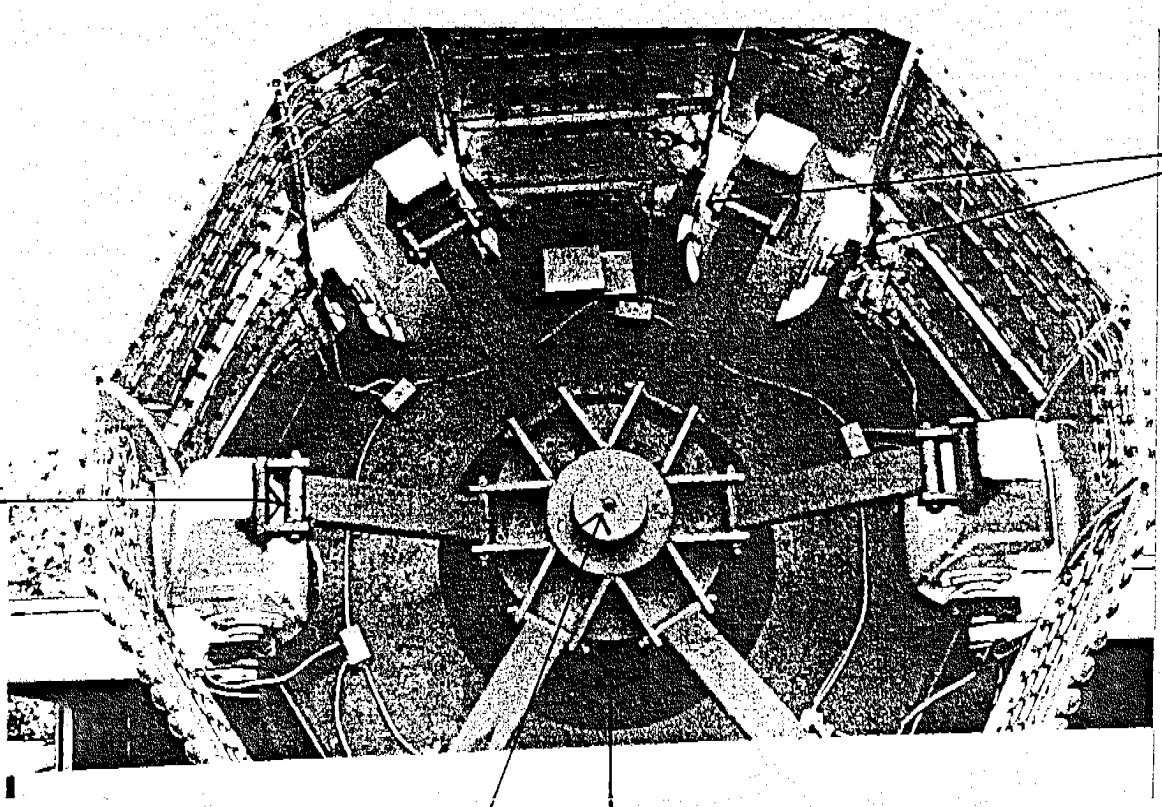
4) CHECK THAT ALL SUPPORT JACKS ARE TIGHT.

5) CHECK LEVEL TO INSURE RIDE HAS NOT SETTLED.

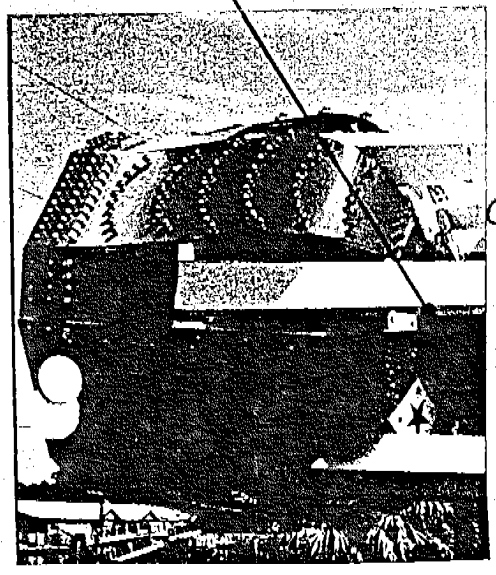
6) CHECK THE GROUND BENEATH THE RIDE FOR SIGNS OF OIL LEAKAGE. IF ANY LEAKAGE FOUND ,NOTIFY RIDE SUP.
(IF EXCESSIVE LEAKS OCCUR STOP RIDE,TURN OFF MAIN BREAKER AND NOTIFY SUPERVISOR IMMEDIATLY.

# WEEKLY SERVICE OF STAR FIRE

AT ALL GREASE FITTINGS INJECT 2 OR 3 PUMPS WITH A STANDARD GREASE GUN.( SEE PHOTOS ) WIPE OFF EXCESS GREASE.

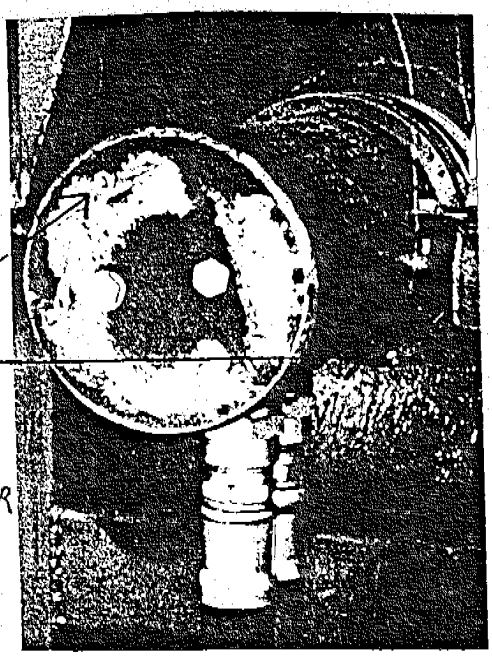



GREASE COLLAR



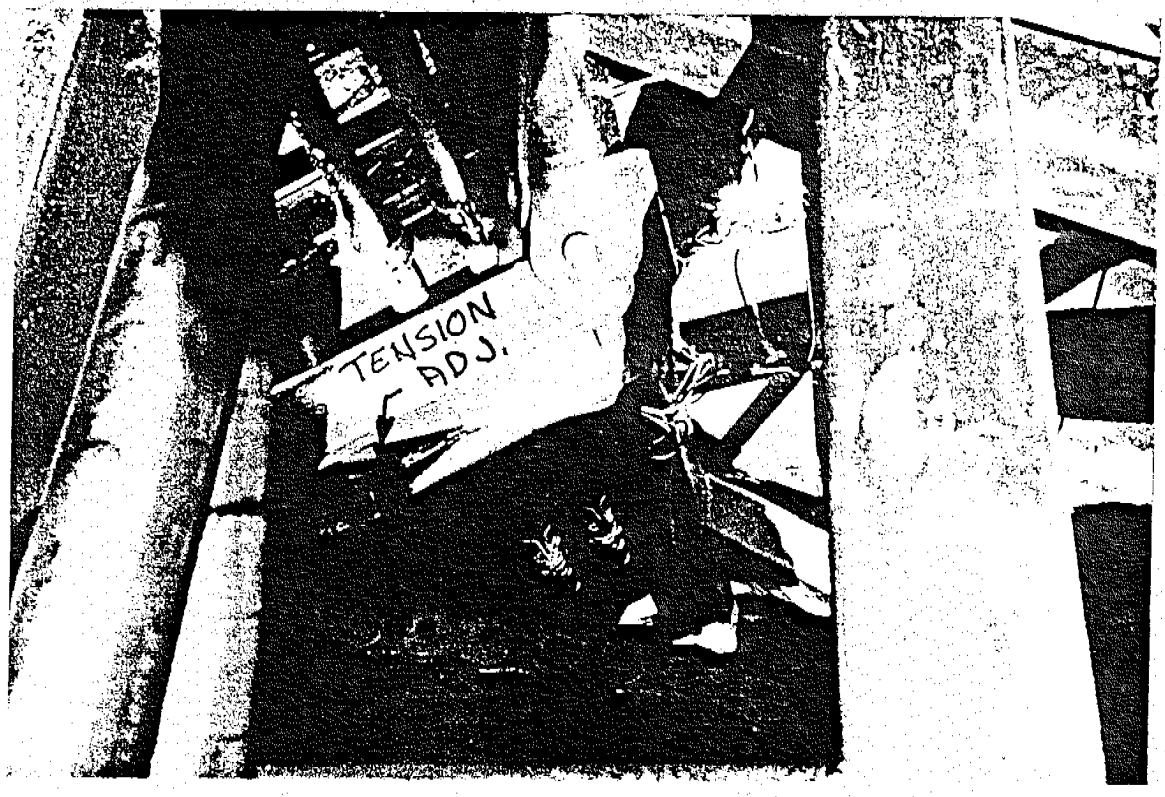
GREASE CYLINDER

GREASE ZOOMER POLE



GREASE OIL CUMMUTATOR

* LUBE THE CHAIN. CHAIN SHOULD HAVE ABOUT 3/4 INCH SLACK IN IT, AND ADJUST TIGHTENER.



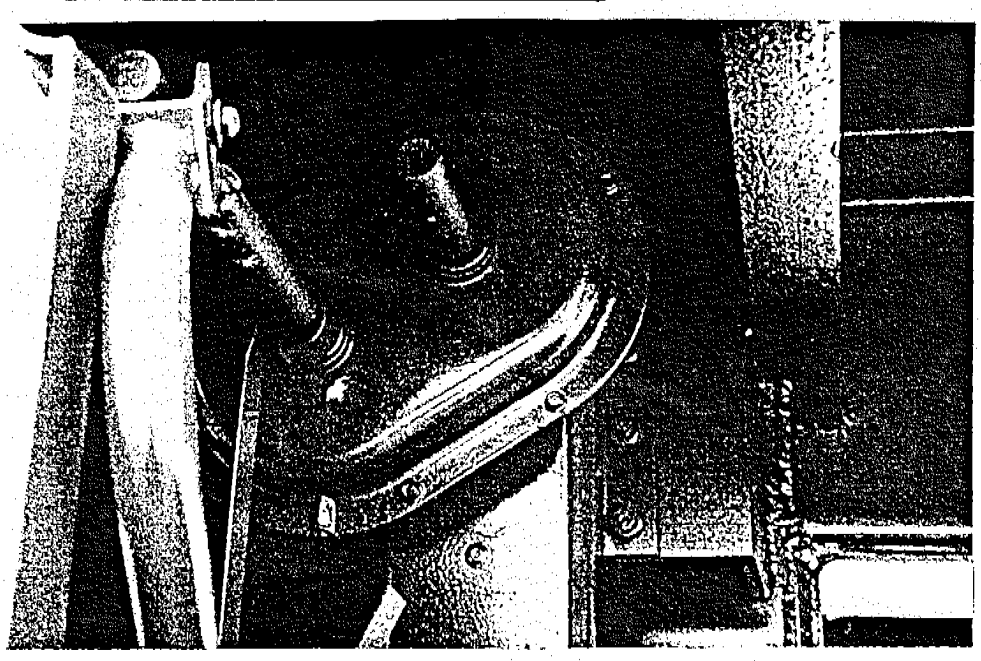

* CHECK HYDRAULIC FLUID LEVEL. FILL TO 3 INCHES FROM BOTTOM OF FILL TUBE.

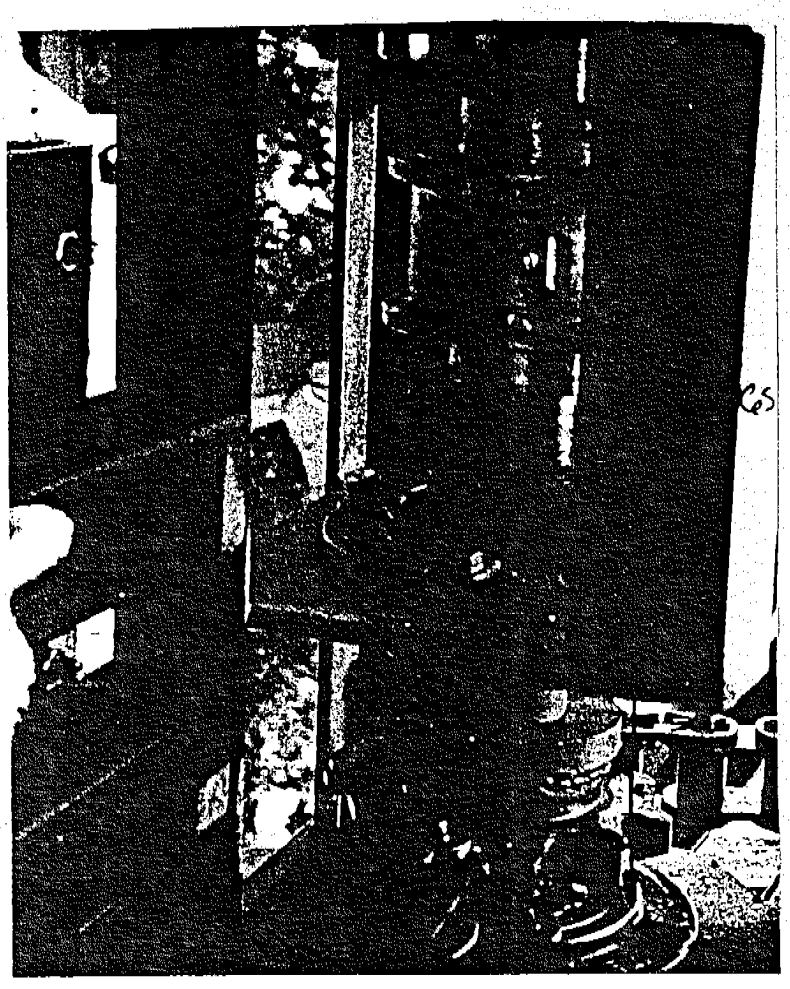
* CHECK TRAILER TIRES FOR CORRECT PRESSURE AND EXCESSIVE WEAR.

* VISUALLY INSPECT SWEEP PIVOTS, CONNECTING RODS AND MOUNTS FOR CRACKS. ALSO CHECK WISHBONES.

****SPECIAL NOTE::: BE SURE TO GREASE MAIN DRIVE BEARING THAT IS LOCATED BELOW THE MAIN DRIVE SPROCKET BEFORE RAISING TOWER. SEE LARGE BLACK ARROW FOR LOCATION ****

GREASE LANDING GEAR WEEKLY



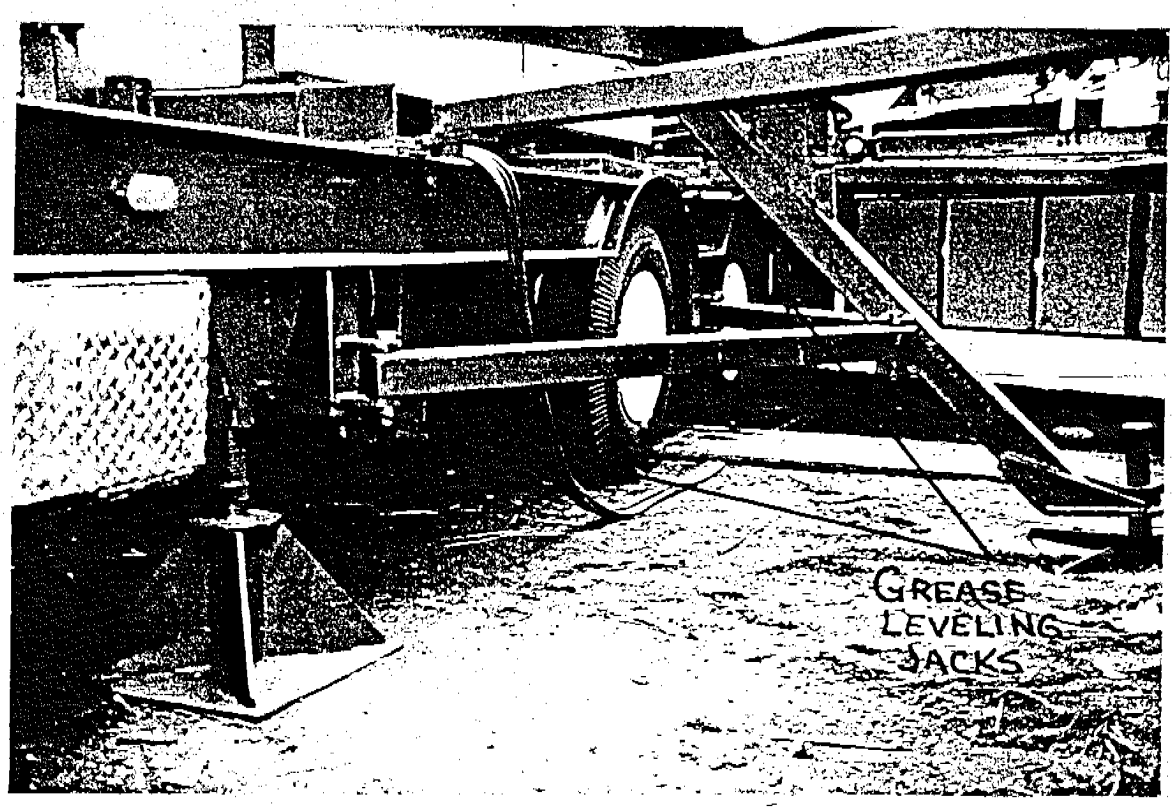


ALSO GREASE

DRIVE BEARINGS

WEEKLY

GREASE LEVELING JACKS WEEKLY



## MONTHLY

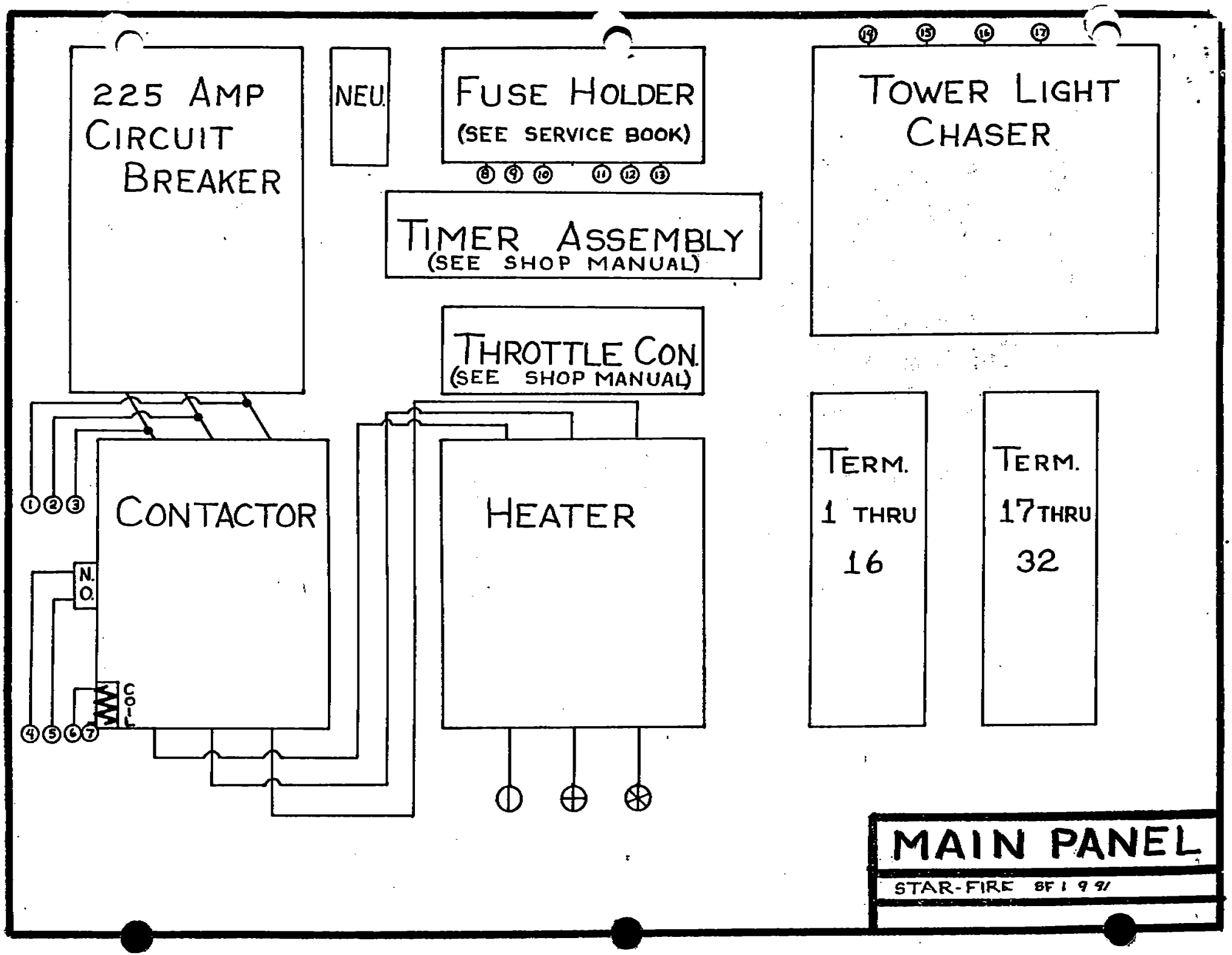
## RIDE SUPERVISOR SERVICES

REMOVE MOTOR COVERS AND ACCESS PLATES, LUBRICATE MOTOR COUPLINGS. REPLACE ALL COVERS FOR SOUND SUPPRESSION.

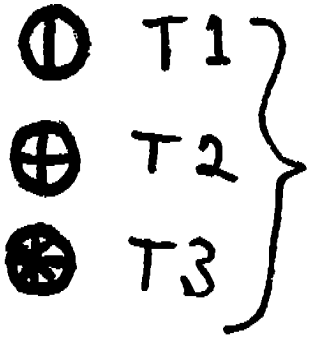
LUBRICATE TRAILER SUSPENTION SYSTEM.

** EVERY 500 WORKING HOURS CHANGE OIL FILTER.

# ELECTRICAL SYSTEM


225 AMP CIRCUIT BREAKER
NEU.
FUSE HOLDER (SEE SERVICE BOOK)
14 15 16 17
TOWER LIGHT CHASER
8 9 10 11 12 13
TIMER ASSEMBLY (SEE SHOP MANUAL)
THROTTLE CON. (SEE SHOP MANUAL)
1 2 3
CONTACTOR
HEATER
TERM. 1 THRU 16
TERM. 17 THRU 32
N.O.
COIL
4 5 6 7
MAIN PANEL
STAR-FIRE BF 1 9 91

MAIN PANEL




1)TO LOAD CENTER & COOLING PUMP

2) " " " "

3) " " " "

4) TO TERMINAL # 3

5) TO TERMINAL # 1/ 28

6) TO TERMINAL # 2 ( STARTER COIL )

7) TO NEUTRAL ( STARTER COIL )

8) TERMINAL # 17

9) " # 18

10) " # 19

11) " # 21

12) " # 22

13) " # 23

14) " # 25

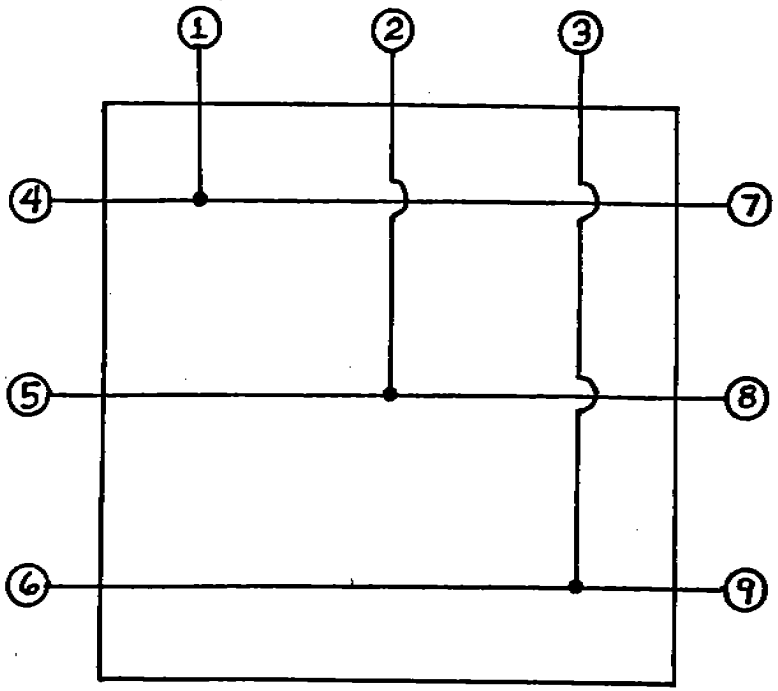
15) " # 26

16) " # 27

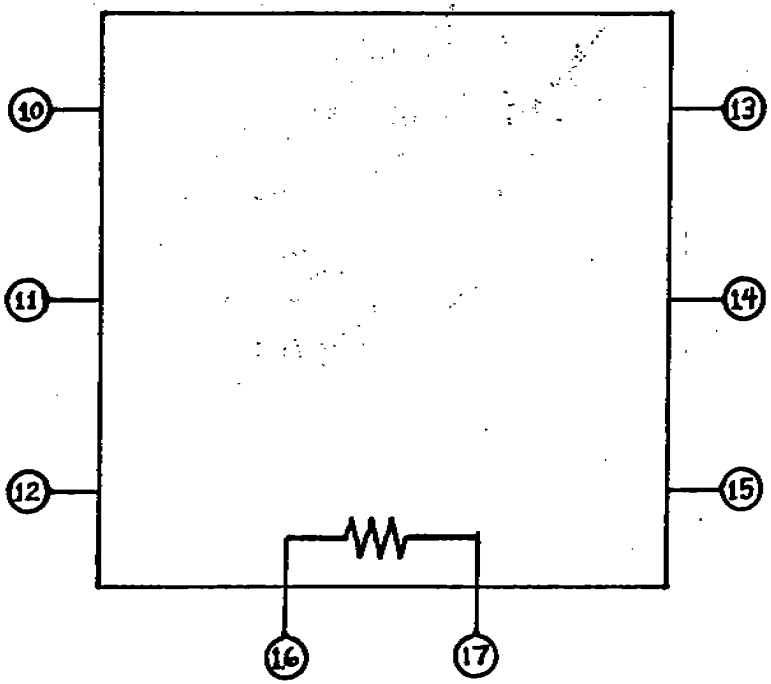
17) " #

18) NEUTRAL

## CURRENT DIVIDER




## AUX. CONTACTOR




# POWER DIST.

STAR-FIRE SF1 991

CURRENT DIVIDER

1) MAIN PANEL ( HEATER)

2) " " "

3) " " "

4) ROTATION DRIVE MOTOR

5) " " "

6) " " "

7) AUX. CONTACTOR

8) " "

9) " "

AUX. CONTACTOR

10)CURRENT DIVIDER

11) " "

12) " "

13) LIFT DRIVE MOTOR

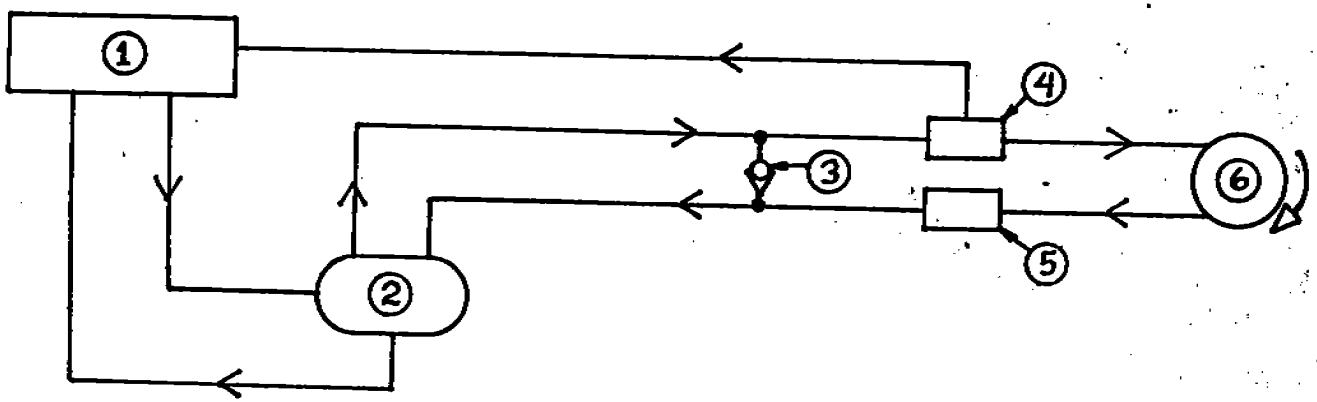
14) " " "

15) " " "

16) TERMINAL # 6

17) NEUTRAL

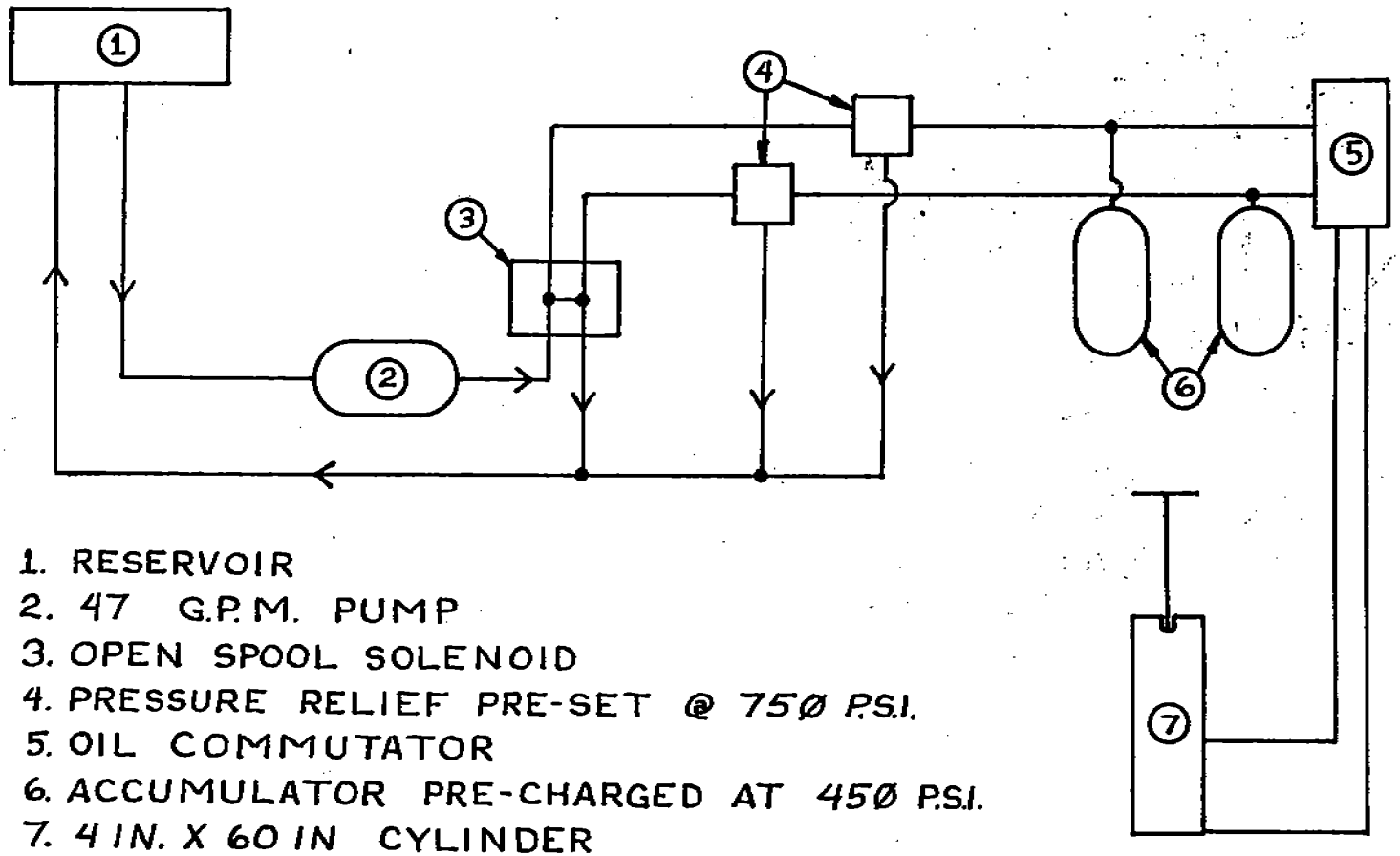
# HYDRAULIC SYSTEM




1. RESERVOIR
2. SERIES 23 SUNSTRAND PUMP
3. DIRECTIONAL CHECK VALVE
4. PRESSURE RELIEF VALVE PRE-SET AT 1700 PSI
5. ELECTRIC BRAKE VALVE PRE-SET AT 500 PSI
6. HYDRALIC MOTOR

HYD. DRIVE

STAR-FIRE SF1 991




1. RESERVOIR
2. 47 G.P.M. PUMP
3. OPEN SPOOL SOLENOID
4. PRESSURE RELIEF PRE-SET @ 750 P.S.I.
5. OIL COMMUTATOR
6. ACCUMULATOR PRE-CHARGED AT 450 P.S.I.
7. 4 IN. X 60 IN CYLINDER

# LIFT SYSTEM

STAR-FIRE SF1 99'