**Transverse Impact on Model Beams of Different Materials**

**Dulal Goldar**

Former Director, Delhi College of Engineering, Delhi, India

# ABSTRACT

Author studied model beams with equal over- hang simply supported like a bridge girder with equal over- hang on either side of supports. Two types of experiments were carried out. First dynamic photoelasticity was carried out to study transverse impact on urethane rubber beam by free fall of a striker from a height of 176.4mm keeping beam- striker weight ratio (2.675) constant. Employing Fastax framing camera (12,000 frames per second) isochromatic fringe photographs were recorded in a light field polariscope for central and non-central impact on simply supported beam with equal over- hang for three different types of spans, namely, 90mm, 120mm and 150mm with three different mass of strikers 10.52gm, 14.02gm and 17.53gm respectively. Beam- striker weight ratio (2.675), height of fall, and dimensions of beam were kept constant.

A contact force transducer was fabricated to measure impact force using quartz crystals, charge amplifier and storage oscilloscope. Second set of experiments were conducted on beams made of three different materials, namely, PMMA, Aluminum and PMMA-AL-PMMA with 120 mm beam span. The mass of striker was to 41.gm for central impact only.

Using electrical resistance strain gauges, contact force transducer peak tensile strain and contact force were recorded.

A nomogram indicating normalized Hertz’s constant striker- beam weight and peak tensile strain for the beams of different materials were plotted. Peak tensile strains in PMMA beam impacted centrally by different strikers were also recorded. Another nomogram indicating normalized Hertz’s constant, striker- beam weight ratio and peak tensile strain for the PMMA beam under central impact were plotted. Presence of small amplitude ‘precursors’ and small-amplitude higher frequency oscillations in the strain histories recorded and identified.

**Keyword list:** Dynamic Photolasticity, Fastax framing camera, Urethane rubber beam, Contact force Transducer,

Electrical resistance strain gauge, PMMA-, Aluminum- a PMMA-AL-PMMA (layered composite) beam, Transverse Impact

# INTRODUCTION

In modern times dynamic stress analysis is becoming increasingly important for various engineering applications. These applications may range from analysis of on- shore and off- shore structures subjected to earthquake, high velocity wind, wave – action and explosive blast loading to analysis of surface and- airborne- transport vehicles and other high speed machinery; and last not the least to estimate stresses in biological system subjected to impulsive loading conditions. Collisions and impact by projectiles can set up dynamic stresses in all these situations. The different time histories of loading can produce different responses to the same system, due both to the variation in the magnitude of inertia forces so generated and also to that in material properties at different rates. Due to its importance from point of engineering design and also from point of a better understanding of material1 properties, the subject of dynamic stress analysis and material engineering have attracted the attention of many research workers in the past. Although significant amount of insight in these respects have been developed, the subject being rather intricate would continue to attract attention of more research workers in future.

**Email:** dulalgoldar@gmail.com

# 1.1 EXPERIMENTAL SETUP

Transverse Impact load was induced with the help of a freely falling striker on a urethane rubber (PSM-4) beam model (size: 253 mm long x 24.3 mm deep x 12.3 mm thick) for photoelastic studies1. Different over- hang ratios, defined as length of over- hang/ total length of the beam were considered for three different spans, namely 90 mm, 120 mm and 150 mm. For the present study, ratio of weight beam between supports and weight of striker was kept constant (2.675).

**1..1.1 System for Generating Impact:** The system for generating impact was essentially consist of an electromagnet (60 V DC, 40 mA), an aluminium guide pipe (200 mm long, 16 mm dia.) and three different strikers for three cases. The assembly of electromagnet (Fig.1) was fixed centrally over ab aluminium plate (540 mm x 302 mm x 3.4 mm thick). Below this electromagnet the aluminium guide pipe was fitted vertically with the help a sleeve of the same material. This sleeve was connected with the bottom of the horizontal plate with three brass screws. At the end of guide pipe, vertical cuts of 30 mm height on diametrically opposite sides were made for recording movements of striker on photographic film negative. The horizontal plate was supported on four vertical mild steel rods of 12.5 mm dia. and 800 mm height. Horizontal position pf the aluminium plate was adjusted with the help of two sets of mild steel rings and clamping screws on each vertical rod. The horizontality of the supporting aluminium plate was checked with help of spirit level. The base Transverse Impact load was induced with the help of a freely falling striker on a urethane rubber (PSM-4) beam model (size: 253 mm long x 24.3 mm deep x 12.3 mm thick) for photoelastic studies1. Different over- hang ratios, defined as length of over- hang/ total length of the beam were considered for three different spans, namely 90 mm, 120 mm and 150 mm. For the present study, ratio of weight beam between supports and weight of striker was kept constant (2.675).

**1..1.1 System for Generating Impact:** The system for generating impact was essentially consist of an electromagnet (60 V DC, 40 mA), an aluminium guide pipe (200 mm long, 16 mm dia.) and three different strikers for three cases. The assembly of electromagnet (Fig.1) was fixed centrally over ab aluminium plate (540 mm x 302 mm x 3.4 mm thick). Below this electromagnet the aluminium guide pipe was fitted vertically with the help a sleeve of the same material. This sleeve was connected with the bottom of the horizontal plate with three brass screws. At the end of guide pipe, vertical cuts of 30 mm height on diametrically opposite sides were made for recording movements of striker on photographic film negative. The horizontal plate was supported on four vertical mild steel rods of 12.5 mm dia. and 800 mm height. Horizontal position pf the aluminium plate was adjusted with the help of two sets of mild steel rings and clamping screws on each vertical rod. The horizontality of the supporting aluminium plate was checked with help of spirit level. The base

**1.1.2 Details of Strikers:** Three different strikers (Fig.2) weighing 10.53 gm, 14.02 gm and 17.53 gm were made of mild steel with a hemispherical tip of araldite. It was intended to produce transverse impact between two nearly similar materials and not widely dissimilar materials such as urethane rubber and mild steel. Therefore, a hemispherical piece of araldite (Ciba CY230 with hardener HY951) was cemented to the mild steel portion on the impacting side of all the three strikers. It may be seen in Fig.2a and Fig.2b that the above strikers had machined cavities which were provided to accurately adjust self-weights for maintaining beam/ striker weight ratio constant (2.675).

**1.1.3 Arrangement of Support for Beam:** The beam with equal over- hang on either side was simply supported over two mild steel wedges (Fig.3). With the aid of slots and clamping screws, the distance between the wedges could be continuously adjusted between 80 mm and 290 mm. this supporting system was clamped on another fixture ( in which coarse and fine adjustments were provided for both horizontal and vertical movements) available with optical bench (Fig.1). For each simply supported beam span with equal over- hang (i.e 90 mm, 120 mm and 150 mm) marking were for central point (on top surface of urethane beam) and two support points (on bottom of beam) were provided with pen- ink. Similar markings were also made for the study of quarter- span (non- central) impact points.

The horizontality of beam- wedge support and verticality of pipe were checked thoroughly.

After these adjustments the model beam was placed as per markings over the wedge support for central as well as non- central cases. For all the three cases for central as well as non- central impact cases and for different strikers the height of fall was kept same, namely 176.4 mm. Accordingly clear gap between top surface of urethane model beam and bottom of aluminium guide pipe marginally adjusted for different strikers employed.

The strikers were kept at the above height by energizing the electromagnet through a DC power supply. A low supply current was maintained to minimise the time delay for de- energizing the electromagnet.

**1.1.4. Arrangement for Fringe Photography:** For photoelastic study a diffused light polariscope was designed. Two sets of plane polaroid and quarter- wave plate (300 mm x 300 mm size) were mounted on square frame made of 3 mm thick plexi glass (PMMA) sheet. The elements were placed in such a way that polariscope may be set in either dark- or light- field arrangements. For illumination of the urethane rubber beam, two Sun Gun-II, 900W were placed side by side and clamped on a fixture of the optical bench. The illumination was made uniform by a combination of a diffuser plate and a Fresnel lens. An interference filter (of band pass less than 100Ȧ (10-8 m) Model- 068, Photoelastic Inc.,USA was used before the Fastax camera lens to render the light monochromatic.

For the present study the optical elements were arranged in such a way as to produce light- field background. This arrangement helped for recording clearly the supports and movement of the falling striker through the slot cut in the guide pipe and also through the gap between the top face of the beam and the guide pipe. Again from this record contact velocity of the striker was determined. Also the clearance between the guide pipe and beam helped to reduce the resistance to the motion of the striker.

**1.1.5. The Fastax Camera:** Wollensak Fastax (16 mm) framing camera7 was used for fringe photography. The camera was operated with atypical framing speed of 12,000 f.p.s (frames per second). For the first trial 120 ft. (36.58 m) length of film used. For subsequent records, however, 60 ft. (18.29 m) length of film were adequate. The object lens of the camera had a focal length of 2.0 inch (50.8 mm), and a maximum aperture of f/2.0. The image of the unloaded beam was first focussed by the parallax method with the help of telescopic-view-finder, and subsequently checked on the film- plane by statically loading the urethane beam model so as to develop a typical fringe pattern.

**1.1.6 Method of Synchronization:** A schematic diagram showing the method of synchronization1,2 used in fringe photography is indicated in Fig.4. Before recording a particular fringe photograph, the following operations were conducted in a sequence:

1. The time of fall of the striker was measured by “starting” a timer circuit by operation of the electromagnet operating switch and “stopping” the timing circuit by a metal foil short-circuiting. The time of fall was used in setting “Event marking” time of the “Goose-Control Unit” (Fig.4).
2. Depending upon the framing speed desired and the total length of the film used, the “Voltage Control” and “Camera time” of the “Goose Control Unit” were then set.
3. The Relay (Fig.4) was at “Normal” position by which the electromagnet was energized.
4. All the laboratory lights were switched off and the Sun-gun toggle switch was switch on.
5. The “Press-button” switch of the “Time-marker” was pressed.
6. The “Micro-switch” (Fig.4) was operated which set the Relay in the “Record” position. The Relay deenergized the electromagnet and simultaneously switching on the “Goose-Control unit”. The “Goose-Control unit” in turn started motors of the framing camera. By the time the striker hit the beam model, the desired camera speed was achieved. The camera was automatically switched off by the “Camera Time” control provided in the “Goose-Control unit”, and therefore, the recording was completed.
7. The “Time-marker” press-button switch and Sun-gun toggle switch were then switched off.

**1.1.7. Photographic Film:** KODAK 2498 RAR (250 ASA) 16 mm roll films were used for fringe photography. KODAK developer, freshly prepared from chemicals, were used developing these film rolls.

Enlarged prints, both continuous and discrete (selected frames), were prepared from film negatives to study the history of fringe formation and to identify precisely fringe orders (Fig.5, 6, 7 and 8).Only photographs showing continuous prints from frame number 0 to 17 are shown for 150 mm, 120 mm and 90 mm beam span for the shake of brevity for central as well as quarter- span impact cases. Enlargement used for selected frames was significantly greater than that used for continuous printing. Some such selected frames (Fig.6 and 8 for central and quarter- span impact cases) were printed compositely along with a transparent millimetre grating so as to facilitate the plotting of free- boundary stress distributions (Fig.9 and Fig.10 for central and quarter- span impact cases for specific instances of impact ) in the beam.

From isochromatic fringes photographs [2], [4], [5] stress wave propagation [8],[11], contact velocity[10] boundary stress and deflection [6] were recorded for both central and non-central impact cases. Utilizing the results it was observed that 120mm beam case [2] to be important from designer’s point of view.

**1.1.8. Discussion of Results for Dynamic Photoelastic Studies:** Paldas [6] reported the mechanism of isochromatic fringe formation in simply supported urethane rubber beams (Hysol 8705) subjected to central impact loading. The collision velocity was 3.02 m/s, and the span- depth ratio and beam- striker weight ratio ranged between 3.97 and 5.87 and between 1.614 and 8.168, respectively. In two of the four cases reported, there occurred two sub- impacts and the remaining two cases single- sub- impact occurred. A systematic study of fringe photographs revealed that the mechanism of isochromatic fringe formation during the early stages of impact was identified for all the cases, namely generation of ‘semi- infinite plate’ behaviour, reflection of stress- waves from bottom- fibre of the beam, and then generation of ‘elastically supported’ beam behaviour. The mechanism of fringe formation during the later stages of impact was different for four cases, depending upon whether a second- sub-impact between the beam and the striker occurred or not.

In the present study[1], [2] a urethane rubber (PSM-4) beam model was subjected to both central- and quarter- span- impact loadings were simply supported with considerable amount of over- hang (over- hang ratio ranged between 0.204 to 0.322), and were impacted with a constant velocity ranging between 1.163 to 1.700 m/s. The span- depth ratios varied between 3.711 and 6.186, while the beam- striker weight ratio was kept constant (2.675). In the present situation a single sub-impact occurred always (Fig.5). This phenomenon is attributed to the inertia over- hang portions of the beam. Comparing the fringe pattern obtained in the present study with that of Paldas [6], it may be stated that the mechanism of isochromatic fringe formation during the early stages of impact remains unchanged irrespective of the generation of ‘semi- infinite plate’ behaviour, reflection of stress waves from the bottom- fibres of the beam and generation of ‘elastically supported’ beam behaviour. This behaviour is expected, since the stress waves would require certain amount of time to travel the distance from the point of impact to the support locations and further onwards, and till such time the support reactions are adequately mobilised, there cannot be any difference in the behaviour of the beam model.

For the situations of quarter- span impact loadings an additional feature could be recognised during the early stages of impact, namely the ‘simple compression’ behaviour. For all the three cases for spans 90mm, 120mm and 150mm studied the quarter- span impact loading took place at the left- quarter- span location, consequently the point of loading had proximity to the left- hand support locations. A direct ‘fringe- link’ between the point of impact and the left support proved the existence of such ‘simple compression’ behaviour. For 90 mm beam span, such a ‘simple compression’ behaviour was most pronounced as compared to 129 mm and 150 mm beam spans. From isochromatic fringe photographs (Fig.7) such ‘simple compression’ behaviour was longest i.e 7.34 ms for 90 mm beam span and was shortest i.e. 2.11 ms for 150 mm beam span. For the 120 mm beam span the duration of such a ‘simple compression’ behaviour was 2.75 ms close to the 150 mm beam span and was quite far removed from that of 90 mm beam span. Thus 90 mm beam case was a special situation.

From enlarged isochromatic photograph as show in Fig.5 and 6 for central and Fig.7 and 8 for quarter- span impact loading a ‘zero- order’ fringe appeared on the top- fibre of the beam during the early stages of impact load, and the ‘elastically supported’ beam behaviour could be identified from the appearance of such zero- order fringes. Since a zero- order fringe at a free- boundary indicates stress- free state, the location of zero- order fringe on the top- boundary have been indicated as location of stress- free point on the top- boundary. From this speed of travel of stress- free point was determined and reported elsewhere [1],[11].

# EXPERIMENTAL STUDY OF TRANSVERSE IMPACT ON ALUMINUM, PMMA & PMMA-AL-PMMA

Next, beams made of two other materials, one metallic (Aluminum) and other polymeric (PMMA) and composite PMMA-Aluminum-PMMA, having identical supports and geometric conditions as the model photoelastic beams, were subjected to central impact loadings for 120mm span simply supported. The weight of the striker, however, was increased to 41.5 gm. The experimental set up is shown in Fig.11. The details are reported elsewhere [1], [11]. The contact force-and strain-histories in these beams were also found out by using a force transducers and electrical stain gauges respectively. Utilizing these data, an attempt was made to correlate the contact force, the maximum tensile stress and a material constant for such simply supported beams with over-hang subjected to low velocity impact (< 2m/s) by a light striker.

**2.1. Peak Tensile Strains in Perspex, Perspex- Aluminium- Perspex and Aluminium beams under Central Impact Loading**

Peak tensile strain for the above three beams were experimentally obtained and presented in Table-1 along with Hertz’s constants between the striker’s tip and beam materials.

## TABLE-1 Peak- tensile Strains in different Beam Materials under Central Impact loadings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Beam Material** | **Hertz’s constant (cm/ gm2/3)** | **Hertz’s constant normalised for**  **impact on Perspex beam** | **Striker weight/ Beam weight** | **Peak- tensile strain obtained**  **from experiments**  **(µ)** |
| Perspex | 7.42 x 10-6 | 1.00 | 0.93 | 853 |
| Perspex-ALPerspex | 7.42 x 10-6 | 1.00 | 0.65 | 747 |
| Aluminium | 1.42 x 10-6 | 0.10 | 0.41 | 128 |

The values of Hertz’s constant have been normalised in respect of the Perspex beam and the striker/ beam weight has been calculated. The values of normalised Hertz’s constant, striker- beam weight ratio and the peak- tensile strains have been plotted in a nomogram and the same is presented in Fig.12.

**2.2 Peak- tensile Strains in the Perspex beam under Central Impact by different Strikers:** A composite plot of strain- histories for Perspex beam impacted by three strikers namely, 14.02 gm, 29.52 gm & 41.50 gm of weight are shown in Fig.15. The Hertz’s constant in respect of araldite and Perspex (corresponding to striker weight 14.02 gm was calculated [1]. In Table-2 striker weight, Hertz’s constant, striker weight/ beam weight and peak tensile- strain are presented.

## TABLE-2 Peak- Tensile Strains in Perspex Beam under Central Impact loadings

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Striker weight (gm)** | **Hertz’s constant (cm/ gm2/3)** | **Hertz’s constant normalised in** | **Striker weight/ Beam weight** | **Peak- tensile strain (µ)** |
|  |  | **respect of striker of 41.5 gm weight** |  |  |
| 41.50 | 7.42 x 10-6 | 1.00 | 0.930 | 947 |
| 29.52 | 7.42 x 10-6 | 1.00 | 0.66 | 815 |
| 14.02 | 9.55 x 10-6 | 1.29 | 0.313 | 361 |

The values of Hertz’s constants have been normalised in respect of striker weight, 41.50 gm, and the striker- beam weight ratios have been calculated. These values of normalised Hertz’s constant, striker- beam weight ratio and peak- tensile strains for the Perspex beam subjected to central impact loadings have been plotted in a nomogram and is shown in Fig.13 for the 14.02 gm striker, the peak- tensile strain for a ‘normalised Hertz’s constant’ of 1.00 has been estimated from a reciprocal relationship between ‘normalised Hertz’s constant’ and peak strain, and the same is also shown in nomogram (Fig.13) with dotted line.

**2.3 Presence of Small Amplitude ‘Precursor’ in the Strain- Histories Record:**

Goldsmith et al.[12] reported the presence of ‘precursor’ in the strain- history recorded with the help of strain- gauges. In the present work also a number of strain- histories were recorded with the help of strain- gauges on the top and bottom boundaries of the beam (with the exception of urethane rubber beam), and are presented in Fig.14 and Fig.15. It may be seen from these figures that a small amplitude ‘precursor’ was generally present in these strain- histories both at the top and bottom boundaries, especially at quarter- span locations. Again, for the urethane rubber beam model, free- boundary stress distributions at selected instants of time were drawn from the fringe photographs and are presented in in Fig.9 and Fig.10. It may also be seen from these figures that a similar ‘precursor’ in the stress- history is also generally present. Paldas [6] reported that at an early stage of impact loading on a simply supported beam (without over- hang), the fringe pattern developed resembled those produced in a ‘semi- infinite plate’ subjected to a line load on the straight edge, producing compressive stresses at the lower edge of the central section. Then the stress waves were reflected from the lower edge of the beam and subsequently developed tensile stresses. The ‘precursor’ recorded in the present study relate to generation of such an opposite state of stress at early stage of impact in that prevailing later on at free- boundary point. In fact it may be seen from Fig.9 and 10 that the magnitude of these ‘precursor’ along the top boundary becomes significant beyond the quarter- span locations and reached a peak- value over the supports. It implies, therefore, that the material employed in preparing these beams should be capable of withstanding significant amount of tensile stresses the top fibres also, especially in the vicinity of support locations.

# ACKNOWLEDGMENT

The author is thankful to the authorities of Terminal Ballistic Research Laboratory, Chandigarh, India for providing all necessary facilities.

# REFERENCES

1. Goldar Dulal “PhotoelasticStudies of Transversely Impacted Simply Supported Beams” Ph.D Thesis by, August 1981, Panjab University.

1. Goldar D., Verma S.P., Paldas M., “Photoelastic studies of transversely impacted beams with over-hang”, Proc. Symposium on 'War -Head Technology' Organized by Terminal Ballistic research Laboratory (TBRL), Chandigarh, March 1983, presented the paper.

1. Goldar D., Sethi V.S., Khurana O.P., Verma S.R.- “Development and Calibration of a Dynamic Contact-Force Transducer” Proc. 40th anniversary meeting, spring meeting, Society for Experimental Mechanics, Cleveland, Ohio, USA, presented the paper and subsequently published in J. Experimental Mechanics, September, 1985, pp.187-190.

1. Goldar Dulal “Dynamic response of transversely impacted simply supported beams with equal overhang”, Proc. VII-Intel. Congress on Experimental Mechanics, Las Vegas, Nevada, USA.

1. Goldar Dulal, “Full-Field Dynamic Photoelastic Studies of Transversely Impacted Beams”, Paper#OS1W0028, ATEM2003, JSME-MMD, Sept. 10-12, 2003, Nagoya, Japan.

1. Paldas, M., “Deflection and Stresses in Simply Supported Beams under Impact Loading”, J. Institution of Engineers (India), Vol: 54, CI 6, July 1974, pp. 219-224.

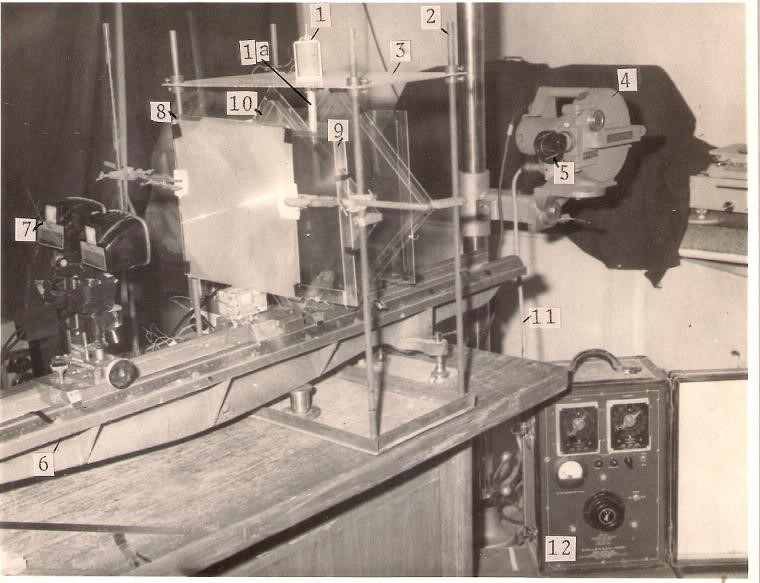
1. Operators Manual, Fastax High Speed Cameras, Category-I through VI, Wollensak division, Co. Rochester, NY, USA.

1. Kolsky, H., Stress Waves in Solids, Dover Publication Inc., 1963, p.84.

1. Kuske Albrecht, Photoelastic Stress Analysis of Machines Under Dynamic Load, Experimental Mechanics, 17(3), March 1977, pp.88-96.
2. Goldar Dulal “Experimental Determination of Contact Velocity” (paper code number A147) 11th Asian

Conference on Experimental Mechanics, 2012 Society for Experimental Mechanics Fall Conference and 7th International Symposium in Advanced Science and Technology in Experimental Mechanics. The conference will take place in The Grand Hotel, Taipei, Taiwan, on November 8-11, 2012.

1. Goldar Dulal “Elastic Wave Propagation in Transversely Impacted Beams” Keynote Speaker, 8th.ISEM, Sendai, Japan November 03-06, 2013.
2. Goldsmith, Warner and Norris, G.W. Jr., Stresses in Curved Beams due to Transverse Impact”, Proceedings U.S. Natl.Congr. Applied Mechanics, ASME, 1958, pp.153- 162.

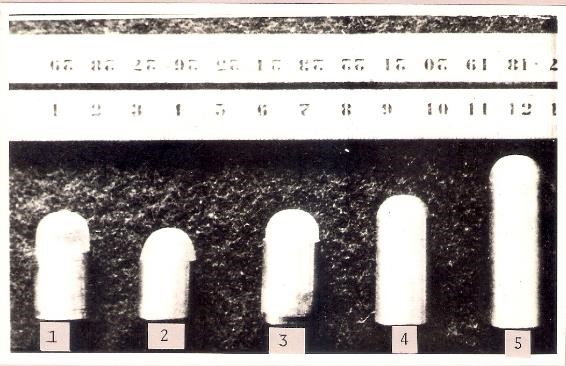
**Legend for FIG.1.**

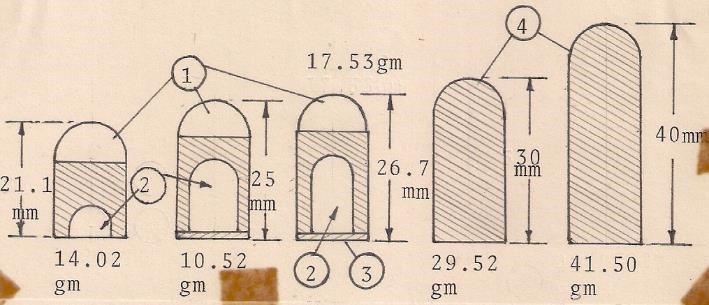
1. Electromagnet (60V DC, 40mV), 1a. Guide pipe, 2.Vertical mild steel rod for supporting electromagnet.

3.Aluminum plate, 4.Fastax, 16mm framing camera, 5.Monochromator, 6.Optical bench, 7.Light source (Sun Gun-II, 800W), 8.Fresnel lens & diffuser plate, 9.Plane polaroid,

10.Quarter- wave plate, 11.Signal from time- marker, 12.Goose control unit.

## FIG.1. Photograph of Experimental Set- up for Dynamic Photoelastic Studies





**Fig.2(a)**

**1**

Araldite hemispherical tip

,

**2**

Cavity for

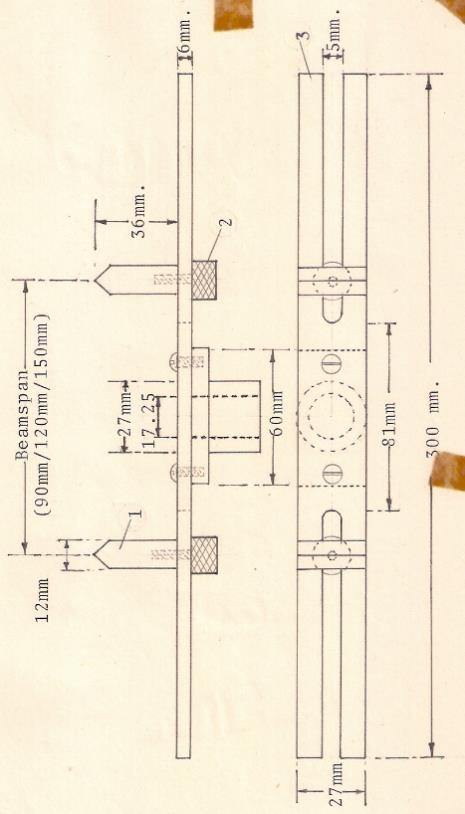
a

djusting weight of

strikers, **3**Mild steel disc for holding properly with electromagnet, **Fig.2(b) 1, 2, 3** Strikers with araldite hemispherical tip of

**4**Mild steel strikers weight 10.52 gm, 14.02 gm & 17.53 gm respectively.

**Fig.2. Different Strikers 4, 5** Mild steel strikers of weight 29.52 gm, 41.50 gm respectively



300

mm

**1.**

Wedge,

**2.**

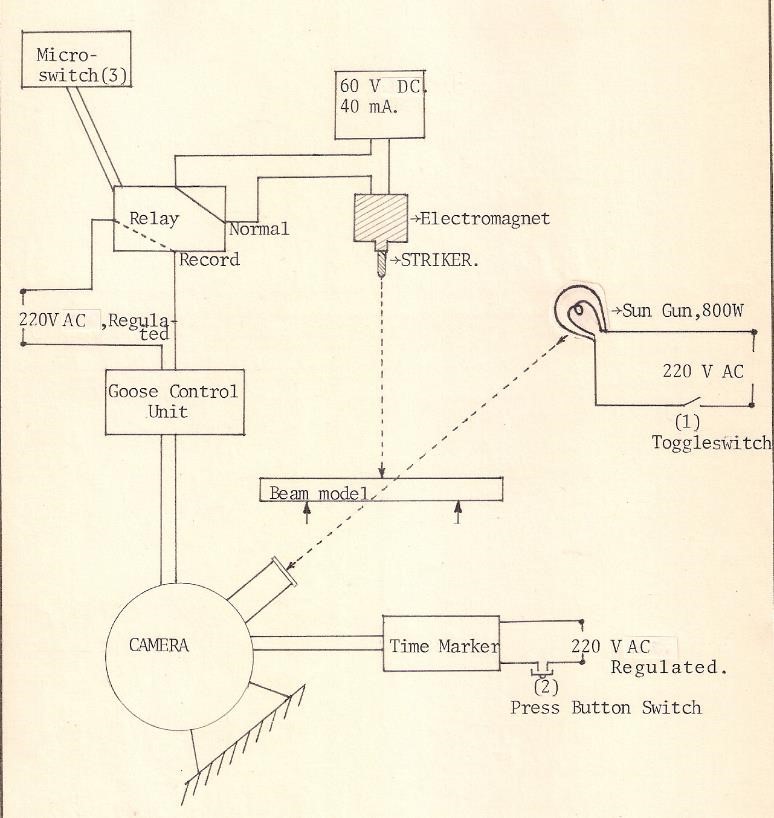
Clamping screw,

**3.**

Beam

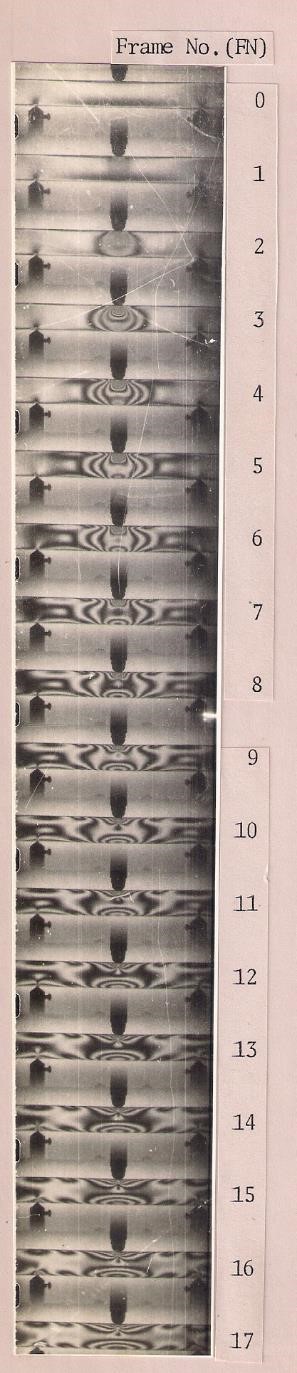
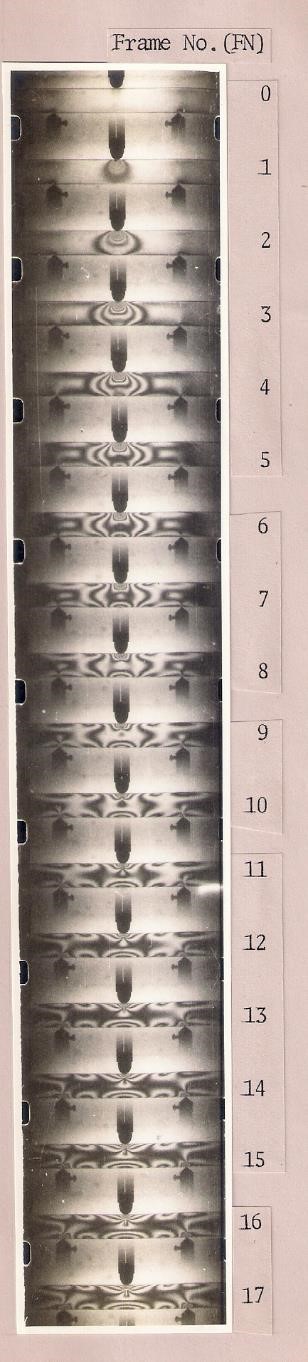
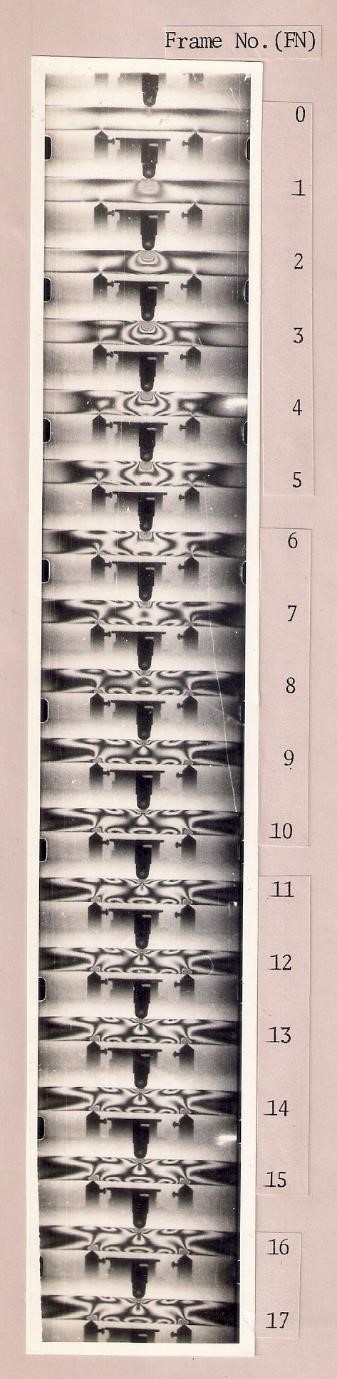
support base

### Fig.3. Arrangement of Support for Beam



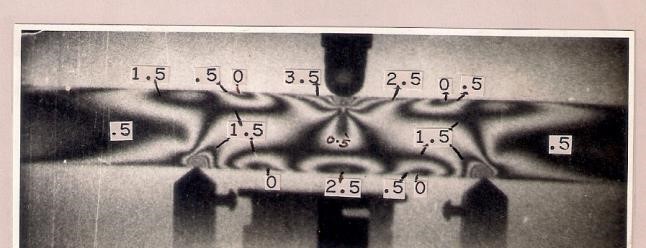
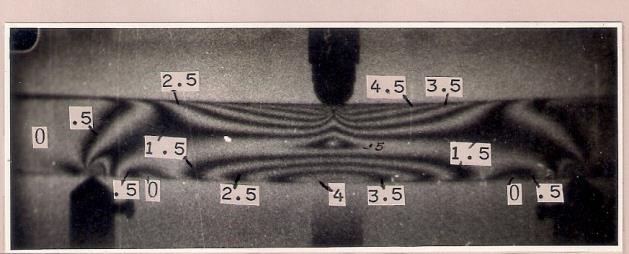
**Fig.4.**

**Method of Synchronization**

150 mm Beam Span 120 mm Beam Span 90 mm Beam Span

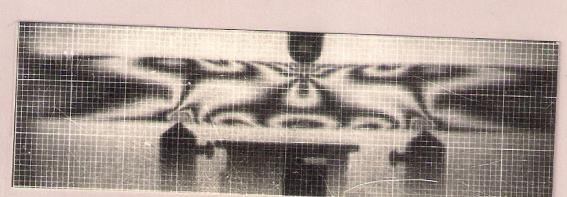
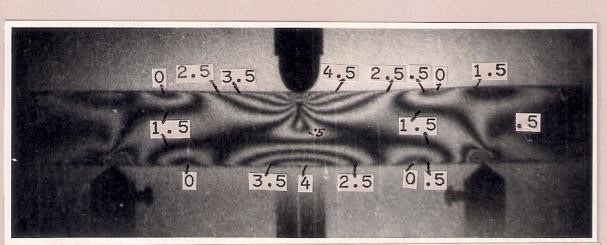
**FIG.5 Isochromatic Fringe Pattern for Central Impact Loading**



**Fig.6 (a) 150 mm Beam Span, Frame No.51, Fig.6 (c) 90 mm Beam Span, Frame No.20,**

**Time = 4936****s. Time = 1897****s.**

**Fig.6 (b) 120 mm Beam Span, Frame No.30, Time = 2523****s.**



**Fig.6**

**(**

**d**

**)**

**90**

**mm Beam Span, Frame No.20,**

**Time = 1897**



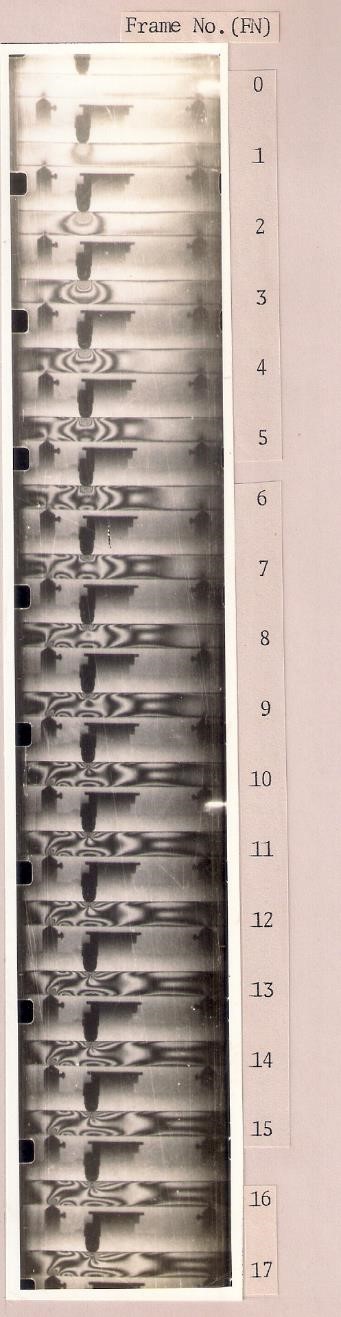
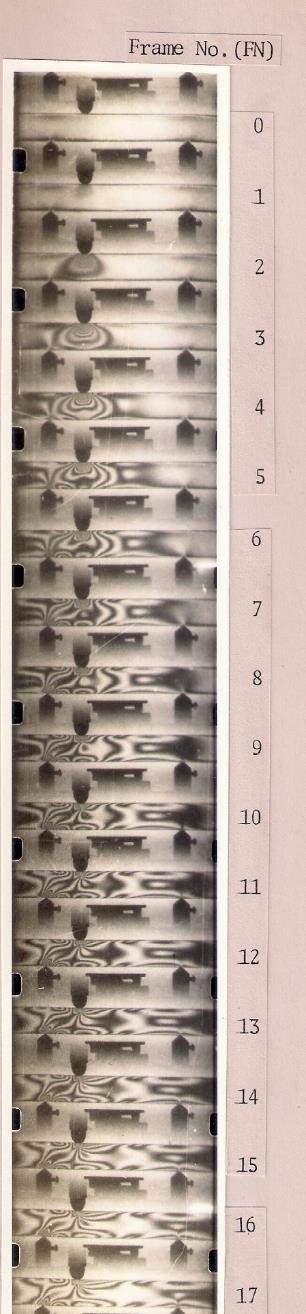
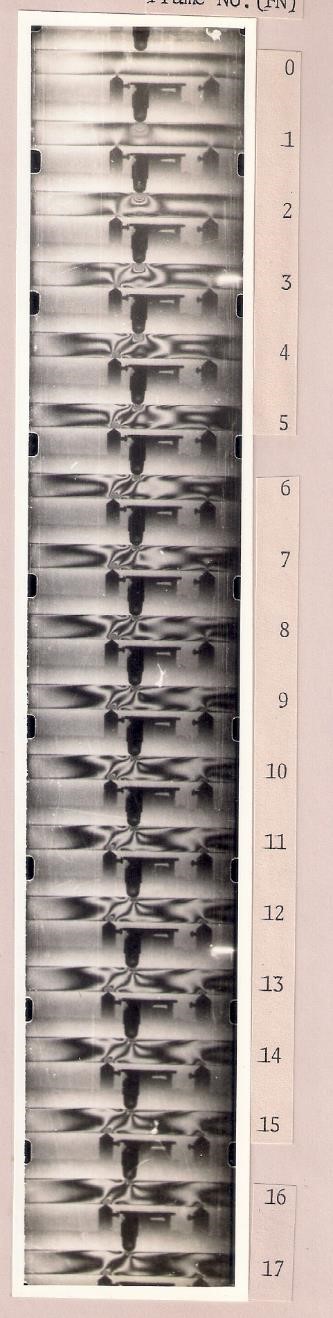
**s.**

**with mm**

**-**

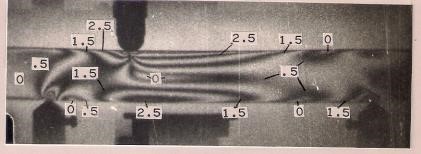
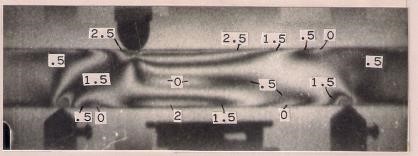
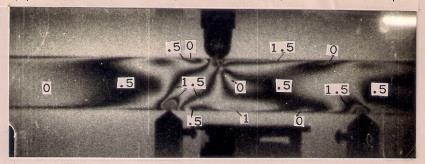
**grating**

**FIG.6 Enlarged Photographs**



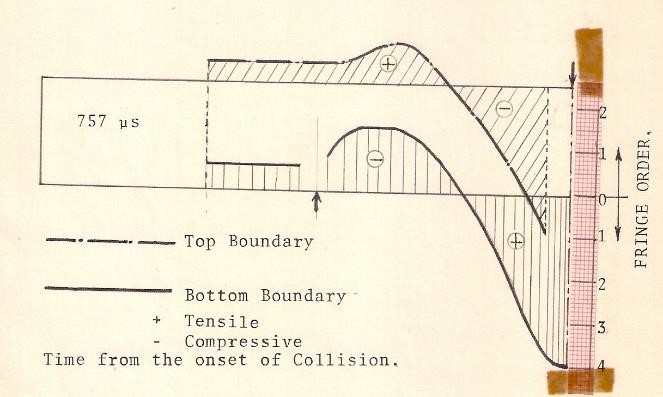
90 mm Beam Span 120 mm Beam Span 150 mm Beam Span

**FIG.7 Isochromatic Fringe Pattern for Quarter- Span Impact Loading**



**Fig.8 (a) 90 mm Beam Span, Fig.8 (b) 120 mm Beam Span, Fig. 8 (c) 150 mm Beam Span, Frame No.13, Time = 1352 µs.** **Frame No. 40, Time = 4238 µs.** **Frame No. 35, Time = 3361 µs.**

### FIG. 8 Enlarged Photograph of Selected Frames



Imp

ac

t Load

**FIG.**

**9**

**. Free**

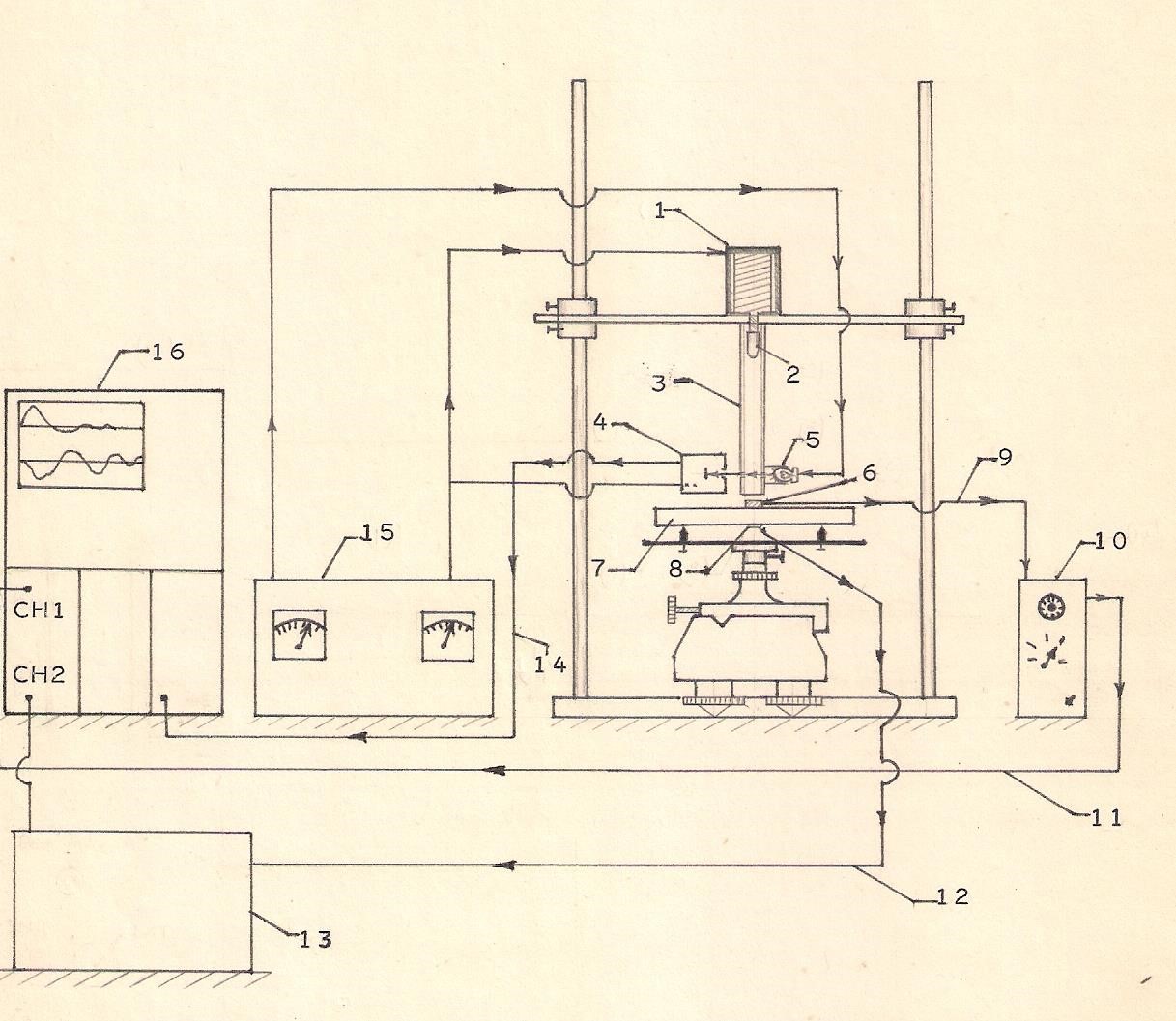
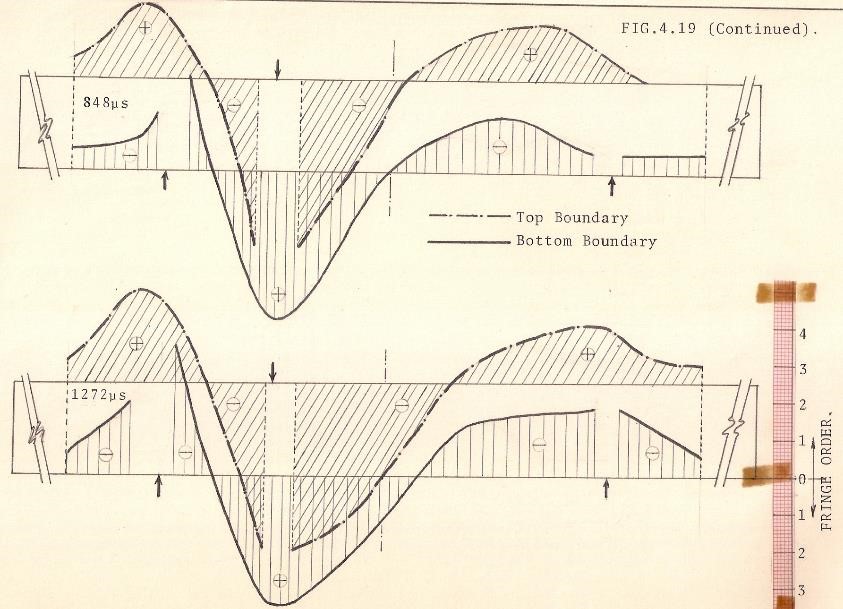
**-**

**boundary Stress Distribution for 120 mm Beam**

**-**

**span**

**under Central Impact Loading**



**Legend for FIG.11**

**:**

1.

Electromagnet (60V DC, 40 mA)

2

. Striker

3.

Guide Pipe

. Photo

4

-

transistor

5.

Light Source (10V DC)

6

. Contact

-

Force Transducer

**FIG.**

**10**

**. Free**

**-**

**boundary Stress Distribution for 120 mm Beam**

**-**

**span**

**under Quarter**

**-**

**Span Impact Loading**

Impact

Load

Impact Load

**FIG.11. Experimental Arrangement for Measurement of**

**Contact**

**-**

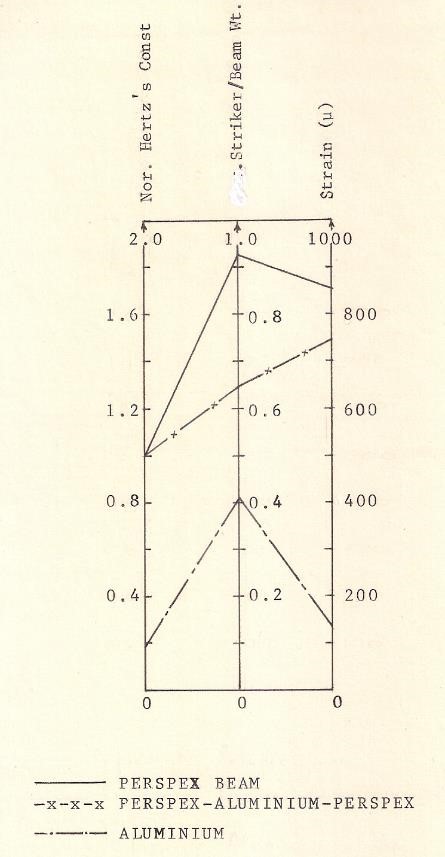
**force, Strain & Contact velocity**

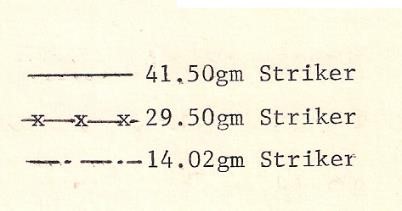
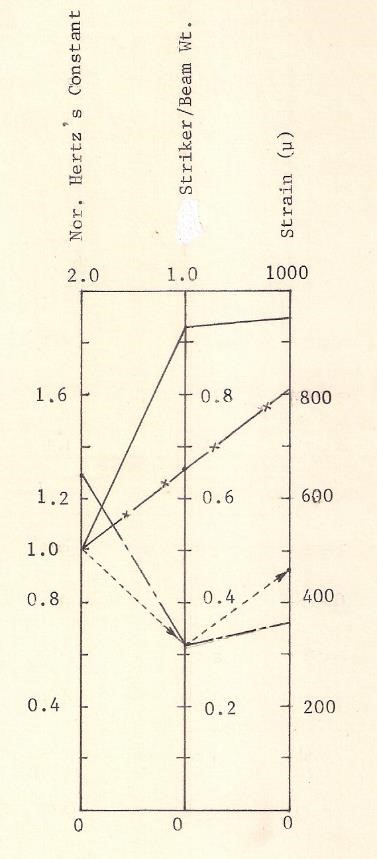
|  |  |
| --- | --- |
| 7. Beam Model  9. Signal from Force-Transducer  11. Signal from Charge Amplifier  13. Bridge Balancing | 8. Strain Gauge  10. Charge Amplifier (KISTLER)  12. Signal from Strain Gauge  14. Signal from Photo-transistor to External |

& Amplifying Unit Triggering of Oscilloscope

15. Variable DC Power Supply 16. Storage Oscilloscope

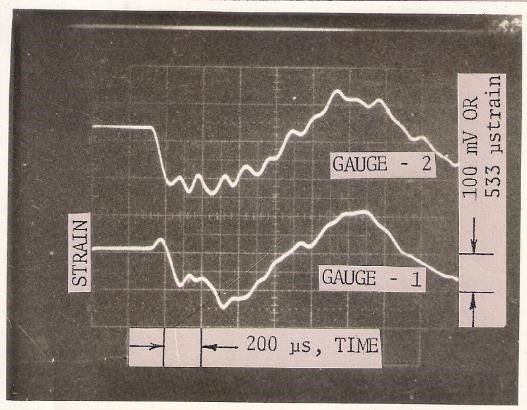
**FIG.11 Experimental Arrangement for Measurement of Contact- Force, Strain and Contact Velocity**

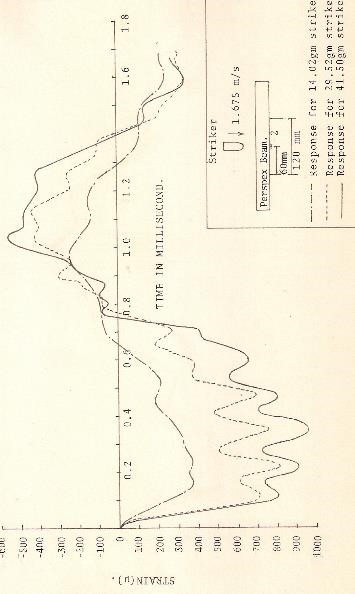
**FIG.12. Nomogram Indicating** **FIG.13 . Nomogram Indicating Normalized Hetrz’s constant,**  **Normalized Hetrz’s constant, Striker- Striker- beam weight ratio & Peak- tensile strain for the Perspex-**  **beam weight ratio & Peak- tensile beam under Central impact loading with different Strikers.**



**strain for the beam of different**

**materials**

**FIG.14. Oscilloscope Traces showing Strain-**



**(**

**a)**

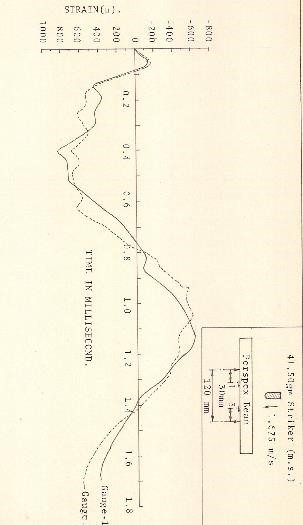
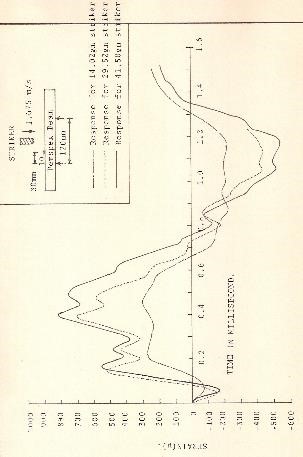
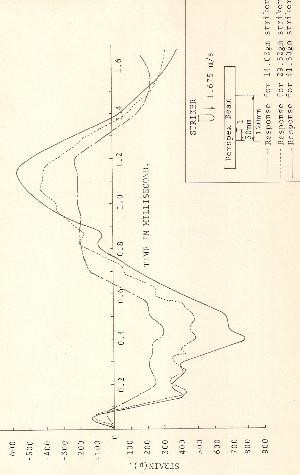
**central**

**-**

**span location**

**histories for Perspex- beam under central impact**  **loading by 41.5 gm striker (mild steel)**

**(** **b) left- quarter span location bottom fibre**  **(c) left- quarter span location top fibre** **for 41.50 gm striker**



**(**

**d)**

**left**

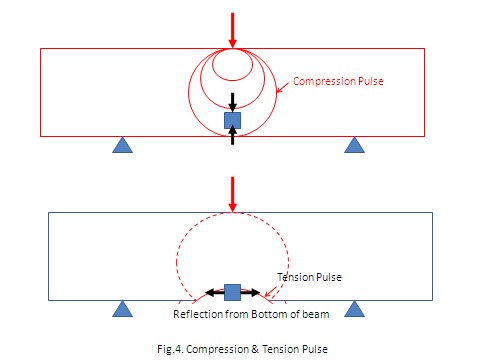
**-**

**quarter & right**

**-**

**quarter span location**

**FIG.15 Composite plot of strain** **- histories at (a) central- span location (b) left- quarter span location bottom fiber (c) left- quarter span location top fiberlocation for 41.50 gm striker**  **for Perspex** **- beam for 14.02 gm, 29.52 gm & 41.50 gm strikers & (d) left- quarter & right- quarter span**



**FIG. 16 Stress**

**-**

**wave**

**propagation**