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STRAIN ACCUMULATION AND SURFACE DEFORMATION ALONG THE SAN ANDREAS, CALIFORNIA

Semi-annual Technical Report
Period: Jan 1, 1989 - June 30, 1989

Grant No. NAG 5-740
Grant Recipient: Massachusetts Institute of Technology
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NASA Technical Officer: Dr. Herbert Frey
Government Grant Officer: Genevieve E. Wiseman

Effective Date of Grant: March 1, 1986
Effective Expiration Date: March 31, 1990

Submitted Date: Oct 1, 1989
Sponsored by the

Crustal Dynamics Program
National Aeronautics and Space Administration

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INTRODUCTION

This is a semi-annual technical report of the project entitled "Strain Accumulation and Surface Deformation Along the San Andreas, California" supported by NASA Crustal Dynamics Program, for the period Jan 1, 1989 - June 30, 1989, based on funding from the Grant No. NAG 5-740 awarded to MIT.

The goal of this project remains to be the achievement of a better understanding of the regional and local deformation and crustal straining processes in western North America, particularly the effect of the San Andreas and nearby faults on the spatial and temporal crustal deformation behavior. Construction of theoretical models based on the mechanics of coupled elastic plate /viscoelastic foundation and large-scale crack mechanics provide a rational basis for the interpretation of seismic and aseismic anomalies and expedite efforts in forecasting the stability of plate boundary deformations.

In the present period, special focus is placed on the three dimensional effect of irregular fault locked patches on the ground measured deformation fields. Specifically, we make use of a newly developed three dimensional boundary element program to analyze the fault slip and vertical ground motion in the Parkfield area on the San Andreas.

SUMMARY OF PROJECT ACHIEVEMENTS TODATE

Major achievements for the duration of the project are summarized below:

1. Developed and completed a model of coupling between the elastic lithosphere and viscoelastic asthenosphere which incorporate the sub-mantle steady state motion as a long term driving force, and the transient loading and reloading of the plate boundary in earthquake cycles. This model suggests significant non-linearity in the stress-accumulation process over an earthquake cycle at a plate boundary.

2. Developed and completed the modeling of crustal deformation (referred to as the Li-Rice model hereon) which varies with time and space at a strike-slip plate boundary embedded in the plate structure described in (1) above.

3. From (1) and (2), and whole cycle San Andreas composite geodetic data, the surface elastic plate thickness is constrained to 20-30 km, and the viscoelastic relaxation time is constrained to 10-16 yr.

4. The predicted surface velocity profiles are in good agreement with geodetic measurements at several locations along the San Andreas where such data is available. Locations studied include Point Reyes area and the Palmdale area. Predicted surface velocity profile at Palmdale area agree with the recently obtained field data. Note that model prediction is made independently of the geodetic field data indicated.

5. Development of a model similar to the Li-Rice model for complex plate boundaries, including plate boundaries exhibiting surface fault creep, and plate boundaries with sub-parallel faults. Application of this model to the Parkfield area in Central California and to the Coachella-Valley area in Southern California is performed. The predicted surface velocity for the Coachella-Valley area can be fitted to recent VLBI and ground based geodetic data.

6. Comparison of the single line dislocation model of Savage and Burford with the Li-Rice model reveals that the locked depth and deep aseismic slip rate are significantly overestimated for the single line dislocation model using geodetic data as constraining information. Further, over the span of an earthquake cycle, the single line dislocation model is shown to predict a shallower locked depth and a larger deep slip rate for a velocity profile associated with a time earlier in an earthquake cycle in comparison to that associated with a time later in an earthquake cycle. This is physically implausible. The suggestion from this analysis is that while the Savage/Burford single line-dislocation model is simple to use and understand, it also imposes severe limitation in direct physical interpretation of fault locked depth and deep aseismic slip rate, as well as other tectonic implications.

Since the last technical report, our work has focused on the study of three dimensional effect of locked patches on the ground deformation field based on a three-dimensional boundary element program developed recently by our research group. The study is made in connection with the Parkfield region on the San Andreas.

INVESTIGATION ON FAULT SLIP AND GROUND DEFORMATION ON THE SAN ANDREAS NEAR PARKFIELD

The fault section of the San Andreas near Parkfield has been the focus of extensive research. This extensive research is mainly due to the relatively short recurrence interval and repeatable character of moderate earthquakes occurring near Parkfield, and the plausible relationship between a Parkfield earthquake and a major rupture. According to Baken and McEvilly (1979, 1984), at least five earthquakes of similar magnitude (M=5.5-6) and epicenter have occurred at 21$\pm$8 year intervals (1881, 1901, 1922, 1934, 1966). Recent works by Rice and others, however, have raised doubts about the regularity issue, and the influence of viscoelastic wave transfer from large nearby ruptures.

The use of mechanical models to study fault regions usually involve the determination of elastic fields due to slip distributions over a predetermined fault surface and can either be kinematic or non-kinematic in nature. Kinematic models use surface deformations near the fault trace as a direct constraint to obtain the slip distributions, irrespective of the ensuing stress distribution on the fault surface. Non-kinematic models use frictional boundary conditions on the fault surface in order to obtain the slip distributions.

Several non-kinematic models of the fault region near Parkfield are available. Quasi 3-D non-kinematic models based on the line-spring procedure were proposed by Li and Fares (1986) and by Tse et al (1985). However, the line spring technique is not considered accurate enough when sudden change in geometry occurs, or when determining the elastic fields at locations that are too close to the fault. A detailed 3-D non-kinematic forecast model of the Parkfield region has been developed by Stuart et al (1985). Their model used slip patches in a halfspace with a free surface and a slip-weakening frictional boundary condition. One of the shortcomings of this model is that the elastic halfspace model cannot account for time dependent viscoelastic effects arising from the presence of the asthenosphere. The assumption of a fully relaxed asthenosphere (resulting in the lithosphere as a free riding plate) also cannot be conclusively demonstrated, especially in view of the relatively short recurrence time of Parfield earthquakes. Nevertheless, a plate model is in general more appropriate than a halfspace model because the recurrence time interval of Parkfield earthquakes of 21 years is longer than the 10-16 years estimated characteristic relaxation time of the asthenosphere (Li and Rice, 1987).

The non-kinematic 3-D model of the fault region near Parkfield is shown in Figure 1. The model assumes slippage to occur over a surface lying in a plate and with simple frictional boundary conditions specifying that all slipping regions have the same constant level of frictional resistance. Such a frictional boundary condition requires the determination of which region of the fault is slipping and which is locked. The determination of the geometry of the slipping region of the fault requires extensive studies and has not been performed. The geometry of the slipping region in the fault region near Parkfield has been determined by referring to previous kinematic studies by Harris and Segall (1987), whereas the length of the slipping (or "creeping") zone north of Parkfield has been determined from surface deformation data along the central section of the San Andreas fault (Figure 2a,b). In determining the geometry of the slipping region of the fault,, the thickness of the plate "H" is taken to be 20-22 km., which implies that the length of the slipping zone is around 8H (i.e. 160-180 km.). Finally, the geometry details at the end x = 8.75 H of the slipping fault region is assumed to have a negligible effect on the fault region near Parkfield, and hence have been assumed to be the simplest possible (as shown in Figure 2a).

FINDINGS

The variation of the surface slip along the fault is shown in Figure 3a. The surface distribution is very similar to the thickness averaged slip of a mode II plane stress crack whose length is around 8.3 H, except along the interval from $0<x/H<1.75$. Along the $0.2<x/H<1.6$, the surface slip consists of a relatively constant surface slip level whose magnitude can approximately be obtained from an antiplane analysis of a doubly cracked plate (e.g. Tse et al, 1985) with a far-field stress of 1.5 to 2 times the actual far-field stress. Rather narrow transition intervals at each end ($0<x/H<0.2$ and $1.6<x/H<1.75$) are observed (Figure 3b). The variation of the lower surface slip is shown in Figure 3c. Note that the lower surface slip distribution does not contain a region for which an antiplane analysis could adequately model the slip variation.

The stress intensity factor (SIF) values in mode III along the upper edge ($z/H=0.05$, $0<x/H<1.75$) shown in Figure 4a and along the lower edge ($z/H=0.5$, $-1.25<x/H<1.75$) shown in Figure 4b are consistent with the observed slip distributions along the upper and lower surfaces. The SIF values also show especially high values near the edge of the semi-locked and through thickness slipping region of the fault (i.e. at $x/H = 1.75$). Finally the mode II stress intensity factors along the edge between the semi-locked and through thickness slipping region of the fault (i.e. $x/H = 1.75$, $0.05<z/H<0.5$) shows (Figure 5) a normalized K_{II} level of around 4.6 which for a nominal crack length of 8.3H implies a far field stress level amplification of around 1.3.

The computed surface uplift values near the fault trace at y/H=0.01 and -0.5<x/H<2.25 are shown in Figure 6. Note that surface uplift values can only be obtained using a 3-D model since uplift occurs due to pinching effects introduced by gradients of slippage along the fault. The maximum change in uplift across the fault trace is at most around 10% the change in surface slip values across the same locations on the fault trace. As expected, the surface uplift is highest at the location where the gradients in surface slippage is highest and reduces to a low level along the interval where surface slip is relatively flat. Finally the surface uplift in the interval -0.5<x/H<1.0 is observed to increase in the negative "x" direction with a small hump at x/H =0.0. This observation could be explained by the relative increase in gradients of slippage that occurs when the semi-locked surface of the fault is locked at its upper edge at x/H = 0.0 (and hence the hump) and then locked at its lower edge at x/H =-1.25 (and hence the gradual increase of surface uplift in the negative "x" direction which is expected to decrease again after x/H = -1.25 is reached).

The above described fault model for the Parkfield region is a preliminary one requiring further extensive parametric studies before comparisons with geodetic surface deformation data can be performed.

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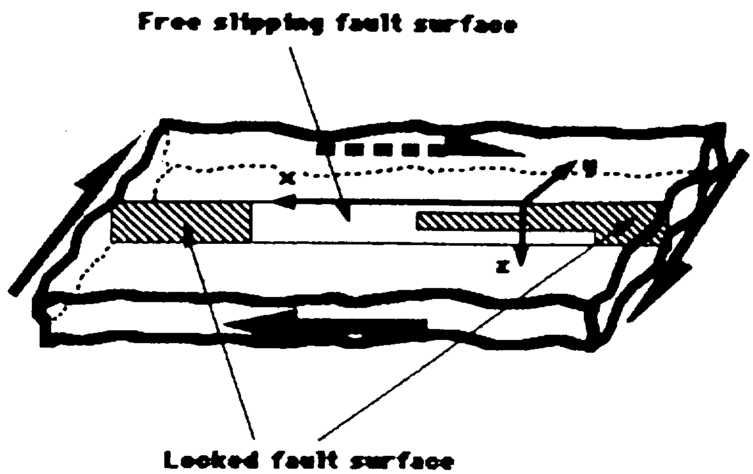

Figure 1

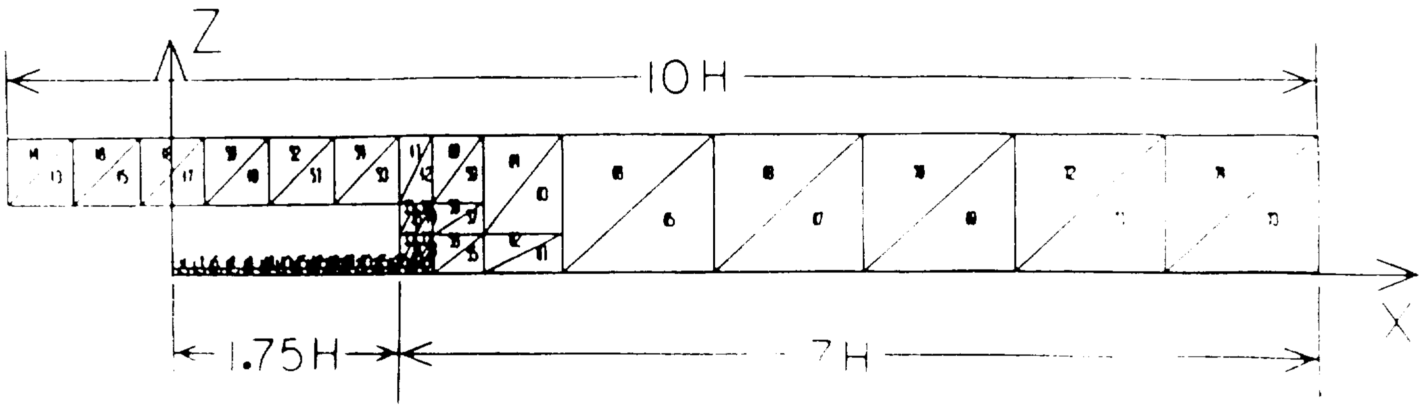

Figure 2a

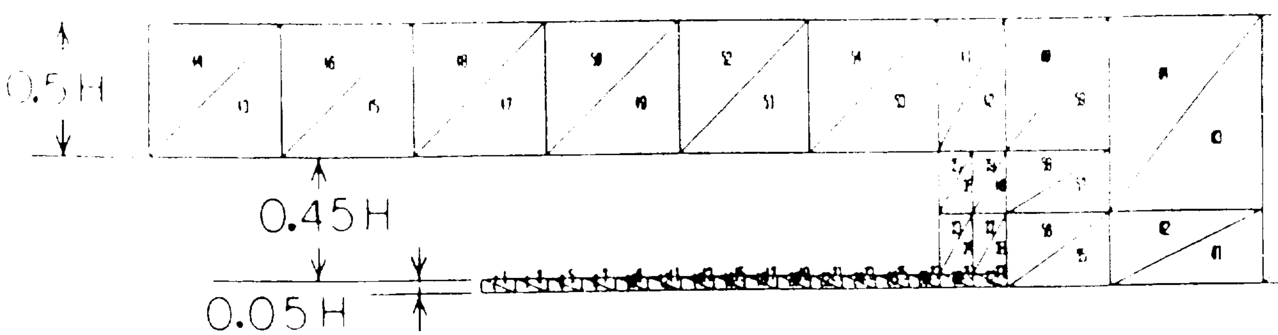

Figure 2b

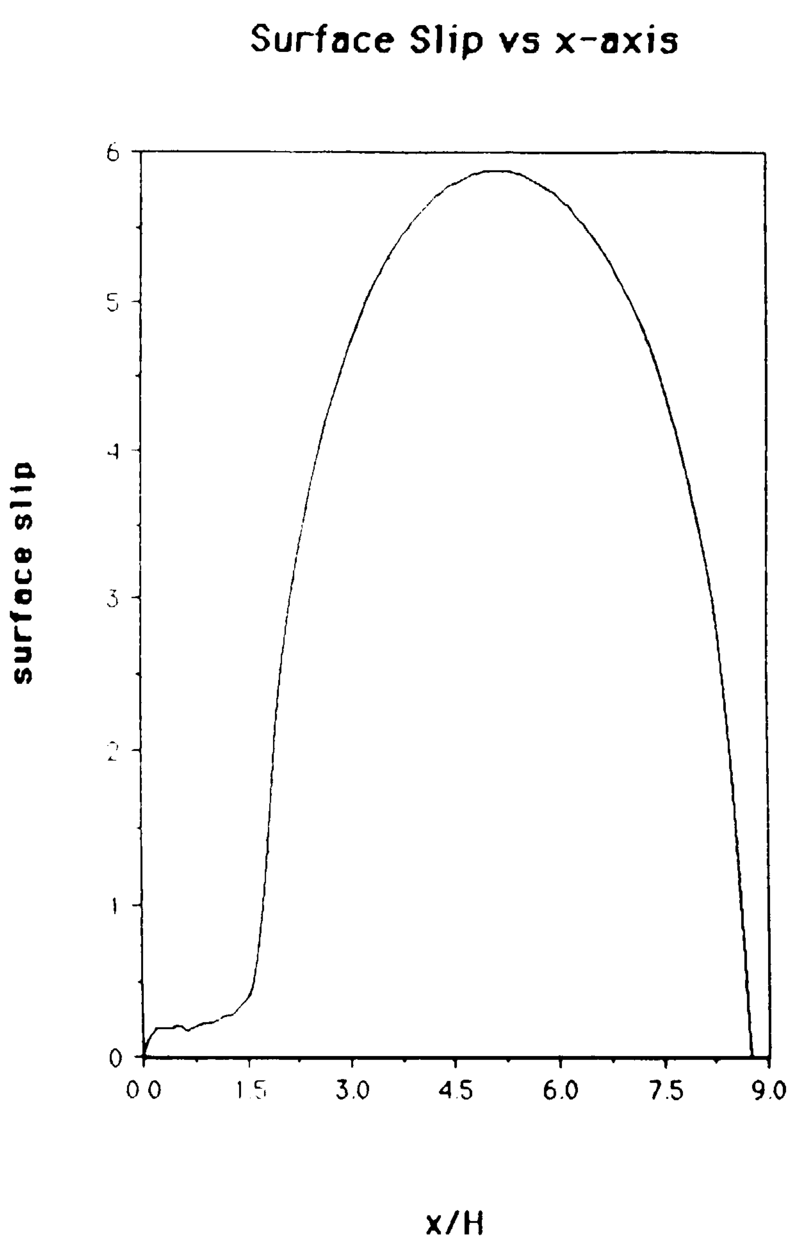

Figure 3a

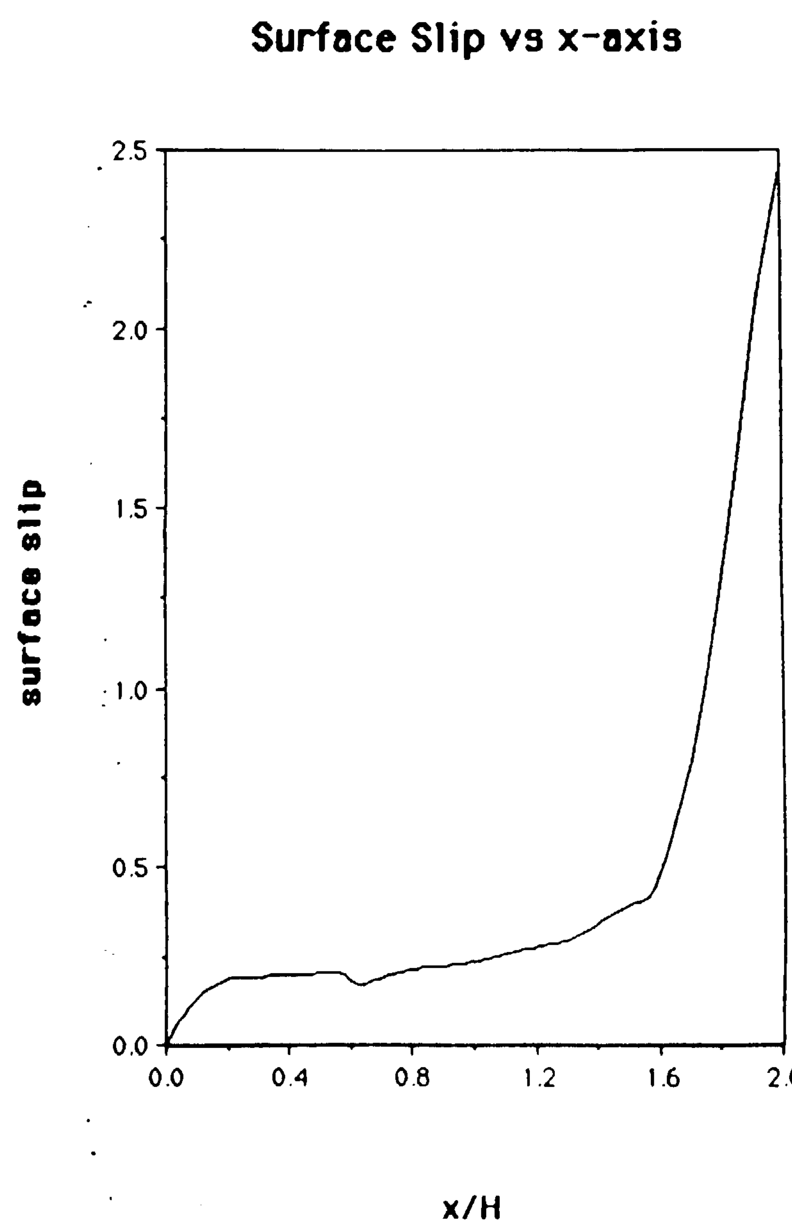

Figure 3b

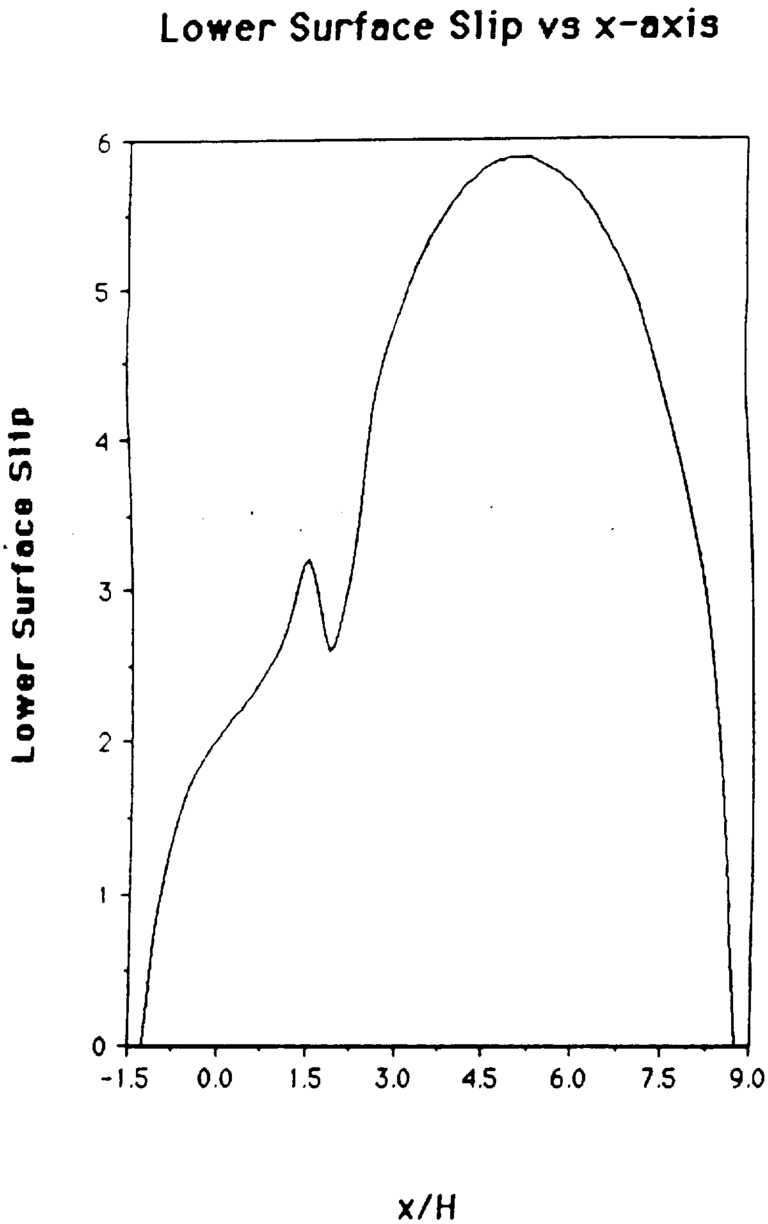
Lower Surface Slip vs x-axis
Lower Surface Slip
0
1
2
3
4
5
6
-1.5
0.0
1.5
3.0
4.5
6.0
7.5
9.0
x/H

Figure 3c

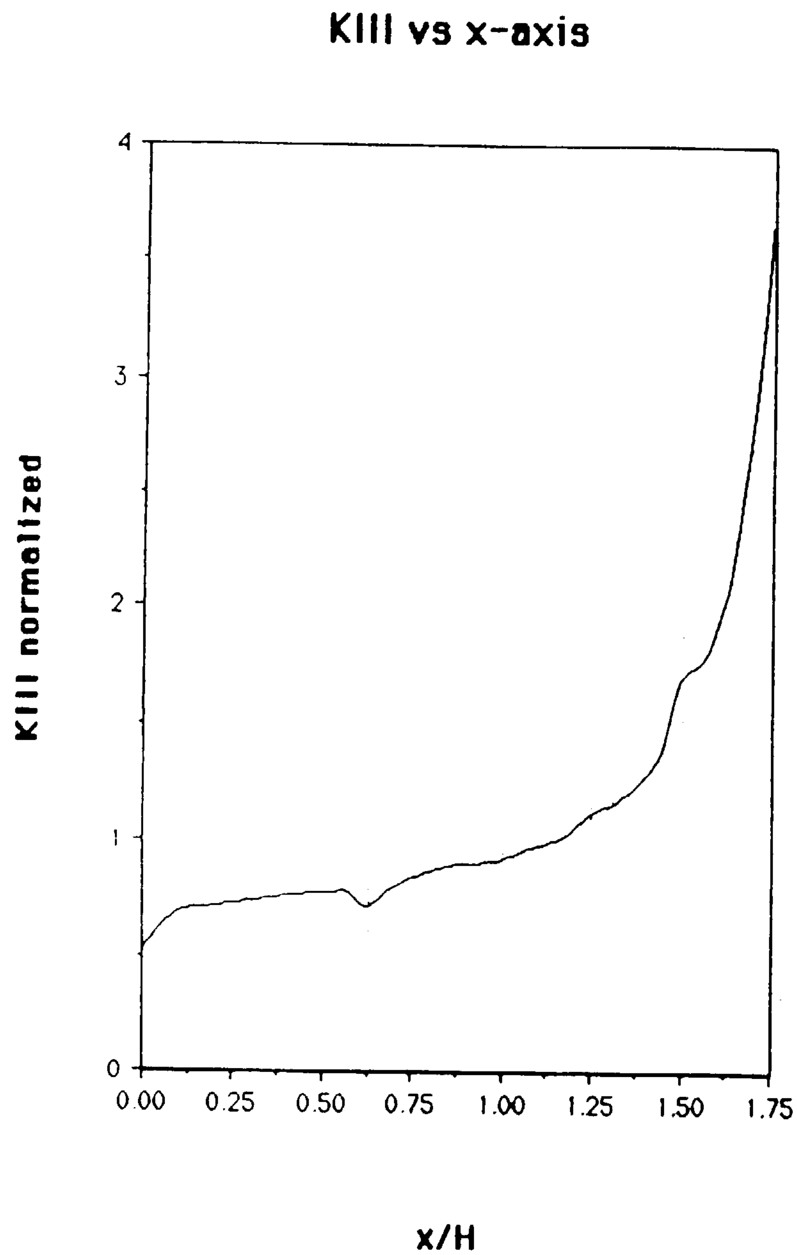

Figure 4a

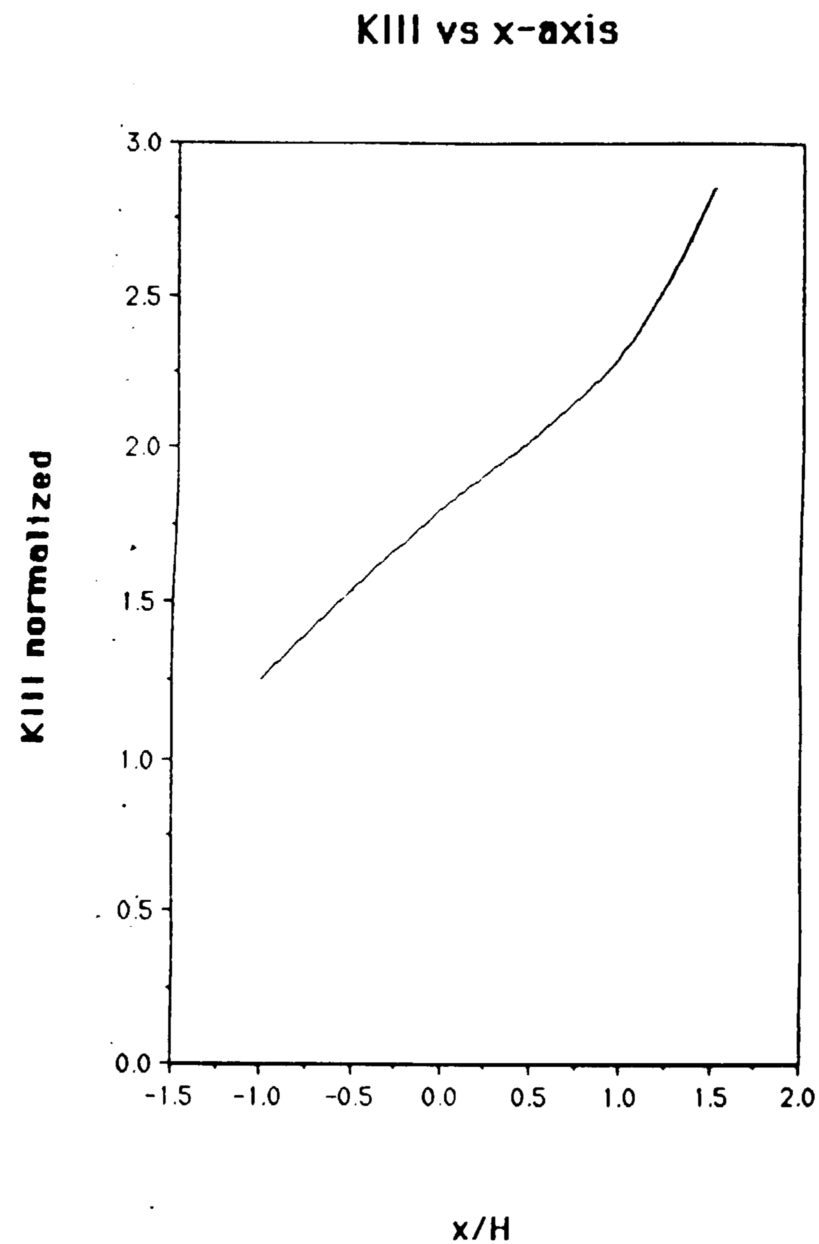

Figure 4b

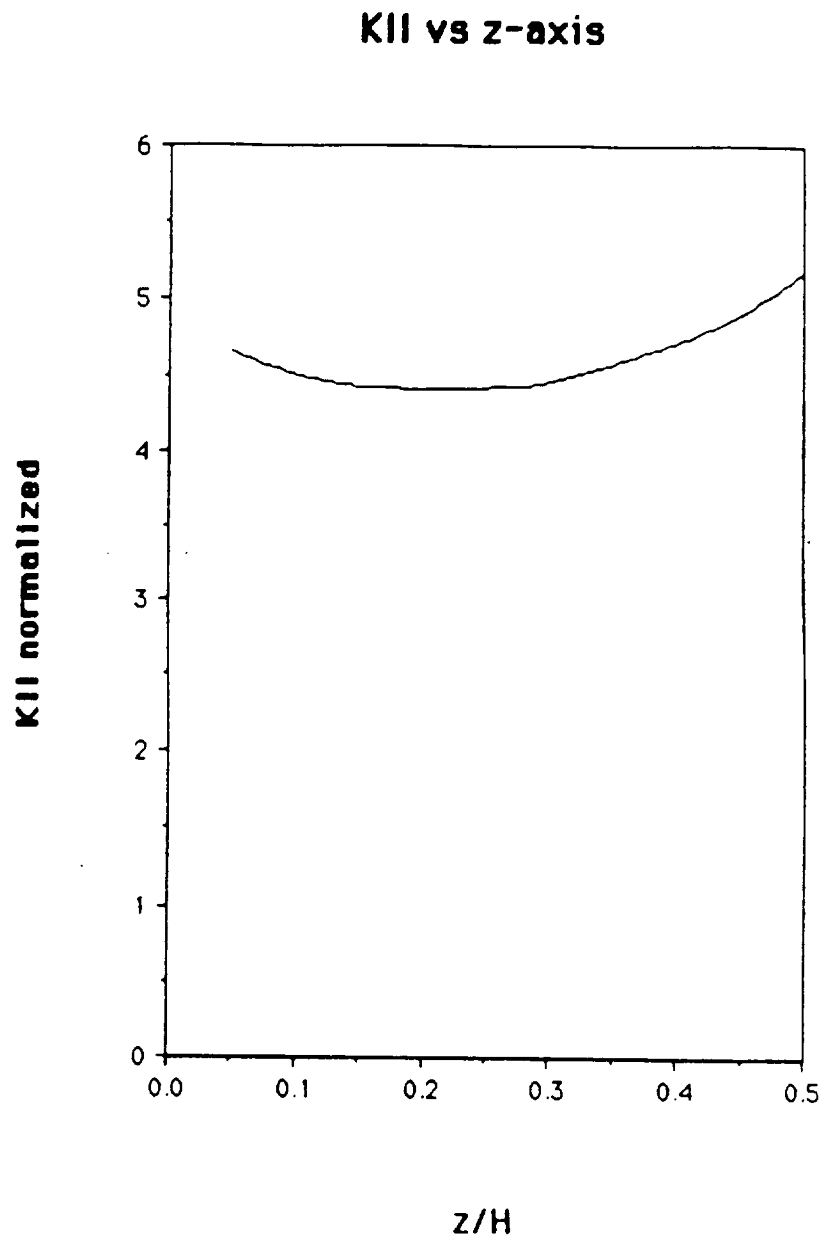

Figure 5

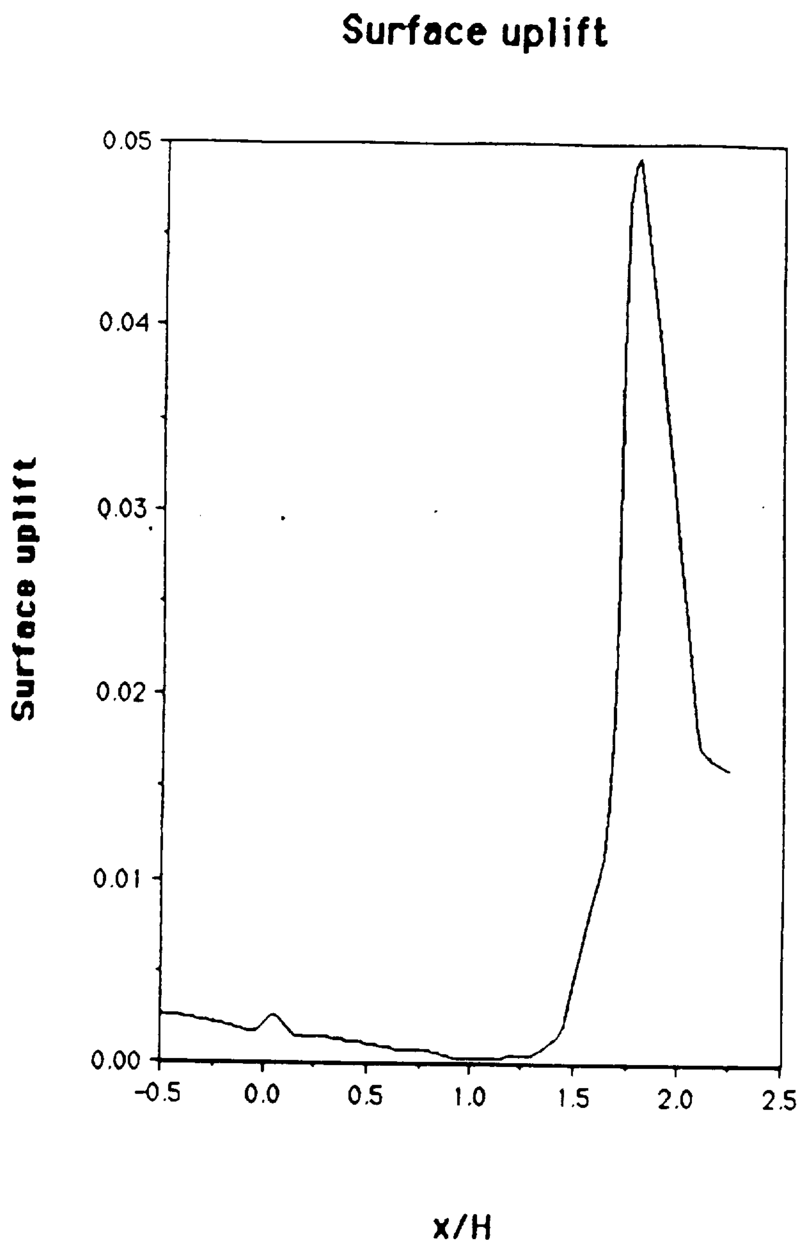
Surface uplift
Surface uplift
0.05
0.04
0.03
0.02
0.01
0.00
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
x/H

Figure 6