A Feedback Model of Geosynclinal Development

Tsuguo Sunamura

A model concerning the temporal development of geosynclines was evolved on the basis of the assumption that a positive feedback relationship existed between two types of vertical forces acting on the earth crust: (1) the time-independent force acting from the earth interior, originating crustal downwarp, and (2) the load of sediments in the depression formed by this original force. The result of formulation by applying linear feedback control theory indicated that this model was characterized by accelerated subsidence. KEY WORDS: Laplace transformation, mathematics, geophysics.

INTRODUCTION

A geosyncline is a large depression generally a few hundred kilometers wide and several hundred kilometers long, in which great thicknesses of sediments have accumulated. The cause of formation of geosynclines has been attributed to the weight of these sediments (Hall, 1859; Russell, 1940). If the theory of isostasy holds, however, it is clear that no such deep geosynclines can be formed by the sedimentary load (Bucher, 1933; Holmes, 1965). Therefore, sediment loading cannot be the primary cause of geosynclinal subsidence (Hsu, 1958, 1965). The primary cause is not yet fully understood; this is one reason that there have been few mathematical models on the temporal development of geosynclines. Recently Fujii and Ito (1973) presented a model which was obtained by assuming the existence of tensile stress acting under the earth crust.

This paper attempts to develop a model, considering two types of vertical forces acting on the earth crust: (1) the force pulling the crust down, that is, the primary force originating crustal downwarp, and (2) the load of sediments in the depression caused by the primary force, that is, the secondary force. It is not the aim of this paper to clarify the mechanism generating the primary force.

1 Manuscript received 21 January 1976.
2 Department of Civil Engineering, University of Tokyo, Bunkyo-ku, Tokyo 113, Japan.

© 1976 Plenum Publishing Corporation, 227 West 17th Street, New York, N.Y. 10011. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, microfilming, recording, or otherwise, without written permission of the publisher.
A FEEDBACK MODEL AND ITS FORMULATION

The assumption of the existence of the primary force leads to the invalidation of the theory of isostasy; this suggests that the sedimentary load works completely as a force depressing the earth crust. Therefore, the following positive feedback relation exists: the primary force originates crustal depression, which in turn brings about sediment accumulation, which causes the secondary force, which promotes the subsidence incorporating with the primary force, and so on. This subsidence model will be formulated by applying linear feedback control theory (Del Toro and Parker, 1960; Kuo, 1962).

The following assumptions are made here: (1) the earth crust is a viscous plate, (2) the primary force, acting on the lower surface of the crust, is time-independent and is distributed uniformly in an elliptical area, (3) the crust in this area is bent downwards, (4) mantle material is of higher fluidity than crustal material, (5) the secondary force is of a uniform distribution over the elliptical area, and (6) there is no time-lag between the subsidence and the sediment accumulation.

Figure 1 is a block diagram showing the feedback subsidence model, where

\[
\begin{align*}
\mathbf{P}(t) & \rightarrow W(s) \rightarrow Z^*(t) \\
& \downarrow \quad \downarrow \quad \downarrow \\
& \rightarrow \mathbf{G}_1(s) \rightarrow \mathbf{G}_2(s) \rightarrow \mathbf{Z^*(t)} \\
& \downarrow \quad \downarrow \quad \downarrow \\
\end{align*}
\]

Figure 1. Feedback subsidence system.

\[
\begin{align*}
\mathbf{P}(t) & \rightarrow W(s) \rightarrow Z^*(t) \\
& \downarrow \quad \downarrow \quad \downarrow \\
& \rightarrow \mathbf{G}_1(s) \rightarrow \mathbf{G}_2(s) \rightarrow \mathbf{Z^*(t)} \\
& \downarrow \quad \downarrow \quad \downarrow \\
\end{align*}
\]

The input-output relation of this system leads to

\[
W(s) = \frac{Z^*(s)}{p(s)}
\]

where \(Z^*(s)\) and \(p(s)\) are the Laplace transforms of \(Z^*(t)\) and \(p(t)\), respectively; \(W(s)\) also can be expressed by

\[
W(s) = \frac{G_1(s)}{1 - G_1(s)G_2(s)}
\]

In order to obtain \(G_1(s)\), consider the open-loop system having the same input, \(p(t)\), that is, the system in which there is no sediment accumulation. Then, \(G_1(s)\) is written as