Computing borehole modes with spectral method
Florian Karpfingr*, Boris Guiveich, Curtin University of Technology, Perth and Andrey Bakulin, Shell Int. E&P, Houston

SUMMARY
We present an algorithm and code that solves the dispersion equation for cylindrical borehole waves consisting of arbitrary number of elastic and fluid layers. The algorithm is based on the spectral method which discretizes the underlying wave equations with the help of spectral differentiation matrices and solves the corresponding equations as an generalized eigenvalue problem. For a given frequency, the eigenvalues correspond to the wavenumbers of different modes. The advantage of this technique is that it is easy to implement especially for cases where traditional root-finding methods are strongly limited or hard to realize, i.e. for attenuative, anisotropic and poroelastic media. We illustrate the application of the new approach using models of a free solid bar and a fluid-filled cylinder. The computed dispersion curves are in good agreement with analytical results, which confirms the accuracy of the new method.

INTRODUCTION
Modelling different wave modes propagating along a borehole is important for understanding and quantitative interpretation of borehole sonic and seismic measurements. All these modes are strongly frequency dependent. Traditionally, mode dispersion was studied by finding roots of analytical dispersion equations. This method has a long history. At the end of the 19th century Ludwig Pochhammer and Charles Chree (e.g. Pochhammer, 1876) independently investigated the wave propagation along an elastic cylindrical bar. The dispersion curves for a free cylinder were computed much later by Senocraft (1941) and Davies (1948). For the case of a fluid-filled borehole, with appropriate boundary conditions, analytical solutions were given by Bloch (1952) and Del Grosso and McGill (1968). The case of a hollow cylinder either empty or filled with a fluid for different tube wall thicknesses, was studied e.g. by Gazis (1959) and Rubino and Keller (1971).

Root-finding is a direct analytical technique and hence the most natural method for analysis of the dispersion. However this method becomes difficult to implement when the numbers of cylindrical layers and modes become large and when inelastic effects need to be taken into account, as separation of different roots becomes challenging.

An alternative approach to modelling wave propagation in cylindrical structures was recently introduced by Adamou and Craster (2004) based on spectral methods. The problem is solved by numerical interpolation using spectral differentiation matrices (DMS). The advantage of this approach is that it is much faster and easier to implement then conventional root-finding methods, especially for anisotropic, poroelastic or anisotropic structures.

In this paper we introduce the spectral method approach for longitudinal wave propagation along the axis of a free circular cylinder. The results are compared with the known analytical solutions from Davies (1948). The approach is then extended to $n$ cylindrical solid and fluid layers. We illustrate the results with the model of a fluid filled tube, which are compared to the results from A. Sidorenko (St. Petersburg State University, Russia) root-finding program based on the parameters used by Del Grosso and McGill (1968). Finally particle displacement profiles, which result from the eigenvectors, are computed. The results for the free cylinder are illustrated and discussed for various frequencies.

THE UNDERLYING EQUATIONS
We introduce the spectral method using the easiest case of longitudinal wave propagation in a free solid bar. Fig. 1 displays the geometry and the displacement field. We use cylindrical coordinates $(r, \theta, z)$. As longitudinal (axisymmetric) wave propagation in a cylinder is independent of $\theta$, the particle motion occurs solely in the $r$–$z$ plane where the displacement $u_\theta$ is parallel to the $r$–$z$ axis and $u_r$ to the $r$–$z$ axis. We consider the propagation of a infinite train of sinusoidal waves along the $z$–axis of the cylinder which is a harmonic function of $z$ and $t$ of the form

$$u_r = U e^{i(k_r z + \omega t)},$$
$$u_\theta = W e^{i(k_\theta z + \omega t)},$$

where $\omega$ is the angular frequency and $k_r$ the angular axial wavenumber. $U$ and $W$ are the amplitudes which are functions of $r$ and $\theta$. From eqs. 1 it follows that $\partial u_r / \partial t = i \omega u_r$ and $\partial u_\theta / \partial z = i k_\theta u_\theta$ etc. The bar is a homogeneous, isotropic, elastic body with $P$- and $S$-wave velocity $(v_P, v_S)$ and density $\rho$.

**Figure 1:** Geometry of a free solid bar, displaying the coordinate system which reduces to $(r,z)$ and the displacement field $(u_r, u_\theta)$ for axisymmetric wave propagation.

The equations describing such a system are known as the Pochhammer-Chree-equations (Pochhammer, 1876) which are presented in detail by Kolsky (1963) and Bancroft (1941). The equations of motion in polar coordinates using displacement potentials are

$$\left( \frac{\partial^2}{\partial z^2} + \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{\partial}{\partial r} \right) + \frac{\omega^2}{v_P^2} \right) \phi = k_r^2 \phi,$$
$$\left( \frac{\partial^2}{\partial z^2} + \frac{1}{r} \frac{\partial}{\partial r} \left( \frac{\partial}{\partial r} \right) + \frac{\omega^2}{v_S^2} \right) \psi_\theta = k_\theta^2 \psi_\theta,$$

where the scalar potential is $\phi$ and $\psi_\theta$ is the $\theta$ component of the vectorial potential. The stress-strain relations for axial-symmetric modes are

$$\sigma_{rr} = \lambda \Delta + 2 \mu \frac{\partial u_r}{\partial r},$$
$$\sigma_{r\theta} = G \left( ik_\theta u_r + \frac{\partial u_\theta}{\partial r} \right).$$
Spectral Method

where $\Delta$ is the dilatation in cylindrical $r-z$ coordinates, $\lambda$ and $\mu$ are the Lamé parameters. Stress-free boundary conditions are assumed at $\theta = \theta_0$ which means $\sigma_{\theta r}|_{\theta = \theta_0} = \sigma_{\theta z}|_{\theta = \theta_0} = 0$. $\sigma_{\theta r}$ is the normal stress in radial direction and $\sigma_{\theta z}$ is the radial shear stress acting in $z$ direction.

In order to complete the set of equations the displacements $u_r$ in $r$-direction and $u_z$ in $z$-direction are defined in a $\phi - k_z$ domain as

$$ u_r = -\frac{\partial \phi}{\partial r} - ik_z \psi_r \quad (6) $$

$$ u_z = ik_z \phi + \frac{1}{r} \frac{\partial (r \psi_r)}{\partial r} \quad (7) $$

These equations fully describe the problem of any free vibrating cylindrical structures in the $r-z$ plane. In the next section a new approach, based on the spectral method, is introduced in order to solve these equations.

METHODOLOGY

The root-finding approach was developed by Pochhammer (1876) and Chree (1889) in the nineteenth century. A general solution to eqs. (2)-(3) is found which is a combination of Bessel functions of different order. Substituting the solution into the boundary conditions yields a homogeneous system of linear algebraic equations. In order to have non-trivial solutions the determinant of its matrix $M$ must be equal to zero, $\det(M(a,b,c)) = 0$. This is called the frequency equation. The roots of this equation yield the dispersion relation $\omega(k)$. Since wave solutions in cylindrical coordinates contain various Bessel functions, it is often quite difficult to find and separate various roots. This gets more complicated in the case of leaky modes or lossy structures where solutions of the dispersion relation should be found in the complex plane.

The spectral method bypasses these difficulties and solves the underlying Helmholtz equations numerically. For elastic wave propagation this was first implemented by Adanou and Craster (2004) who investigated circumferential waves in an elastic annulus (motion independent of $r$ and $z$; see Fig. 2). In this study we extend the spectral method to axisymmetric longitudinal models.

The initial idea by Adanou and Craster (2004) is to use spectral DM’s to discretise the wave equations and boundary conditions. Then they can be solved as a matrix eigenvalue problem. The resulting eigenvalues correspond to a wavenumber $k_z$ for a given frequency $\omega$ or vice versa. In the following section we illustrate the process of discretisation for the case of the free solid bar using eq. (2).

Subsequently the method is straightforwardly extended to the case of arbitrary n-layered fluid-solid media. The eigenvectors correspond to the potentials $\phi$ and $\psi_r$ which are finally used to compute the mode-shapes.

DIFFERENTIATION MATRICES

In order to solve the Helmholtz eq. (2) numerically we use DM’s to represent the differential operator $L_{\omega}$s. Consider a function $f(x)$ evaluated at $N$ interpolation points, which is represented in a vector $f$ of length $N$. This interpolated function $f$ is connected to its $n$th derivative $f^{(n)}$ through the following equation

$$ \begin{pmatrix} f_1^{(n)} \\ f_2^{(n)} \\ \vdots \\ f_N^{(n)} \end{pmatrix} \approx \begin{pmatrix} D_{11}^{(n)} & D_{12}^{(n)} & \cdots & D_{1N}^{(n)} \\ D_{21}^{(n)} & D_{22}^{(n)} & \cdots & D_{2N}^{(n)} \\ \vdots & \vdots & \ddots & \vdots \\ D_{N1}^{(n)} & D_{N2}^{(n)} & \cdots & D_{NN}^{(n)} \end{pmatrix} \begin{pmatrix} f_1 \\ f_2 \\ \vdots \\ f_N \end{pmatrix}. $$(8)

This means that an approximation of the $m$th derivative of $f$ can be calculated by multiplying $f$ with the $N \times N$ matrix $D^{(m)}$, which represents the DM. The DM’s are calculated by using Chebyshev polynomials. The $N$ interpolation points, which are, in our case, along the radius $r$ of the cylinder, are the $N$ roots of the Chebyshev polynomial of the $N$th order. The Chebyshev DM’s are calculated using the recursive formula for the derivatives of Chebyshev polynomials. The advantage of this approach is that the derivatives of the polynomials can be computed exactly.

The interpolated $r$ vector and the calculated DM’s are now used to represent the differential operator $L_{\omega}$ (eq. 2) in form of a $N \times N$ matrix

$$ L_{\omega} = D^{(2)} + \text{diag} \left( \frac{1}{r} \right) D^{(1)} + \text{diag} \left( \frac{\omega^2}{c_r^2} \right). $$

In the same way matrix representations for all equations of motion and boundary conditions are constructed.

FORMULATION OF THE EIGENVALUE PROBLEM

In order to solve the now numerically interpolated equations as an eigenvalue problem they have to be combined in one matrix equation. First the equations of motion $\nabla^2 u_r$ and $\nabla^2 u_z$ are combined in the $2N \times 2N$ matrix

$$ P = \begin{pmatrix} L_{\omega} & 0 \\ 0 & L_{\omega} \end{pmatrix}. $$

The stress components $\sigma_{rr}$ and $\sigma_{zz}$ are grouped in a matrix of the same size

$$ S = \begin{pmatrix} \sigma_{rr}^{\psi_r} & \sigma_{\theta r}^{\psi_r} \\ \sigma_{\theta r}^{\phi} & \sigma_{zz}^{\phi} \end{pmatrix}, $$

where each component is separated in terms of the displacement potentials $\phi$ and $\psi_r$.

The last step is to combine the boundary conditions with the equations of motion in an appropriate way. As the problem is solved for a hollow cylinder with a very small inner radius which is a limiting case for a solid cylinder, we have to consider inner and outer boundary conditions. This means that the elements of $S$ representing the interpolation points of the inner and outer boundary (1, $N$, $N + 1$ and $2N$) replace the corresponding rows in the $P$ matrix which is now referred to as $\tilde{P}$. The eigenvalue problem can now be formulated in the form

$$ \tilde{P}u = \lambda^2 \tilde{Q}u, $$

where the stress-free boundary conditions are set inside the matrix $\tilde{Q}$. This is a generalized eigenvalue problem and can be solved, for instance using the MATLAB routine eigs($\tilde{P}$, $\tilde{Q}$).

CYLINDRICAL LAYERING

This approach can be straightforwardly extended to $n$ cylindrical fluid and solid layers (see Fig. 2). Each of the $n$ layers has $P$- and $S$-wave velocities $(v_p, \nu_p, v_s, \nu_s)$ and densities $\rho_1-\rho_n$. For each of these layers the matrix $P_k$ is computed in analogy to eq. (10). These equations are finally combined in a diagonal matrix of the size $n2N \times n2N$ which has the form

[334] SEG/San Antonio 2007 Annual Meeting
Spectral Method

The second example (Fig. 4) is a two-layer model: a fluid-filled hollow cylinder. The dispersion curves were originally calculated by Del Grosso and McGill (1968). Here the dispersion curves were computed by A. Sillersom using the ray-tracing technique analogous to Del Gроссо и McGill (1968). Again we were able to reproduce these results accurately using the spectral method. Note that in this case there exist two fundamental modes starting from zero frequency: first one (ET0) is commonly referred to as a tube wave or Stoneley wave, whereas second (ET1) is an analog of a (Longitudinal) plate wave. The mode ET1 only weakly depends on the fluid properties and disappears when the thickness of the cylinder wall increases to infinity or the outer boundary of the cylinder becomes rigid (Rn).

Figure 3: Dispersion curves of a free solid bar: x-axis: wavenumber-radius product, y-axis: phase velocity \( v_p = \alpha / k \) normalized by the bar velocity \( v_b = E / \rho \) where \( E \) is the Young's modulus (compare with Davies, 1948, Sec. 11, Fig. 13);

Figure 4: Dispersion curves for a hollow cylinder filled with non-viscous fluid. Thickness of the cylinder wall: 0.125m; Modes ETn in elastic tube with stress-free outer boundary are shown in red, whereas mode Rn for pipe with rigid outer boundary are shown in blue. Phase velocity \( v_p \) is normalized by the velocity of the fluid \( (v_{\text{fluid}}) \) compare with Del Grosso and McGill (1968).

MODESHAPES: PARTICLE DISPLACEMENT PROFILES

Solving the eigenvalue problem yields the eigenvalues which allow to construct the dispersion curves. At the same time the eigenvectors are computed representing the potentials \( \phi \) and \( \psi \). They allow the
Spectral Method

![Displacement profiles](image)

Figure 5: Particle displacement profiles of the fundamental longitudinal mode \( L(0,1) \) for (a) 500 Hz (b) 2000 Hz, (c) 5000 Hz, (d) 10000 Hz. x-axis: normalized \( u_r \); y-axis: normalized \( u_r \) displacement; z-axis: bar radius from 0 m (center of bar) to 1 m (surface of bar).

The computation of the modes, i.e., the distribution of field quantities like displacements, stresses, power flow, etc., along the radius of the cylinder. Exemplarily, we illustrate the displacements \((u_r, u_z)\) here which can be easily computed using the eigenvectors and eqns. (4)-(5). In order to display the particle displacement profiles \(u_r\) and \(u_z\) are calculated along the radius for a certain frequency. These values are normalized by the maximum absolute value of the \( u_r \) displacement. Finally, the radial displacement is plotted as \( u_r = [u_r] \) and the longitudinal displacement as \( u_z = [u_z] \).

**DISPLACEMENT PROFILES OF THE \( L(0,1) \) MODE**

For the illustration of the displacement profiles we have chosen the fundamental mode \( L(0,1) \) propagating in a free solid cylinder (see Fig. 1). The particle motion \( u_r \) and \( u_z \) is computed for four different frequencies (500 Hz, 2000 Hz, 5000 Hz and 10000 Hz). The insert plot in Fig. 5-d shows the position of the frequencies on the dispersion curve. Fig. 5-a-d displays the displacement profiles for \( u_r \) and \( u_z \) for the different frequencies.

For low frequencies like 500 Hz (Fig. 5-a) the wave propagates like a longitudinal wave. Consequently, the particle motion is in axial direction mainly and uniform throughout the radius of the cylinder. The radial displacement is very small.

In Fig. 5-b we can see that for 2000 Hz the \( u_r \) displacement has already significantly increased all over the cross section. It only remains zero in the center of the cylinder. At the same time the \( u_z \) displacement decreases but keeps its maximum value in the center.

For a higher frequency (5000 Hz; Fig. 5-c) it can be observed that the shape of the displacement profiles propagates slowly towards the typical pattern of Rayleigh modes. Close to the surface \((r=0.65 \text{ to } 1\text{m})\) the motion is already Rayleigh-like. Only towards the center of the bar especially the \( u_r \) component is still relatively strong.

Finally in Fig. 5-d we get the typical particle motion profile of Rayleigh waves. In contrast to Fig. 5-c the amplitudes of both displacement components decreases significantly for \( r < 0.8\text{m} \).

Summarizing, we can say that the displacement field for the \( L(0,1) \) mode can be modeled using the spectral method like expected, which is another proof that the approach works properly.

**CONCLUSIONS**

We extended and implemented the spectral method for propagation of axi-symmetric longitudinal modes in a cylindrical bar. The method was also generalized to N-layered cylindrical fluid-solid structures typical for borehole environment. Dispersion curves for a free solid cylinder and a fluid filled tube were computed and compared with analytical solutions. Furthermore, the displacement profile for the \( L(0,1) \) were computed using the eigenvectors and displayed for different frequencies. The advantage of this approach is, that in contrast to traditional methods, it is easier to implement, especially for cases where root-finding becomes complicated. For cylindrical geometries the spectral method is a good alternative as the produced results are accurate and the computational time is very short. The method is well-suited for extension to anisotropic, alternative and poroelastic borehole structures.

**ACKNOWLEDGEMENTS**

We are grateful to Prof. Boris Kashtan (St. Petersburg State University, Russia) who suggested the idea of applying the spectral method to the problem at hand. We thank Shell International Exploration and Production for support of this work. We thank Alexander Sidorov (St. Petersburg State University, Russia) for the computation of some dispersion curves using his root-finding program. We would also like to thank Prof. Richard Craster (Imperial College London) for his helpful advise at the initial stage of the project.
EDITED REFERENCES
Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2007 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES
Pockhammer, L., 1876, On the propagation velocities of small oscillations in an unlimited isotropic circular cylinder: Journal fuer die reine und angewandte Mathematik, 81, 324.
ACOUSTICS

BG 1.1 (0298-0302)
Acoustic signatures of crossflow behind casing: Downhole monitoring experiment at Teapot Dome
Andrey Bakulin*, Shell Int’l E&P; Valeri Korneev, Lawrence Berkeley Nat’l Lab

BG 1.2 (0303-0307)
First sonic-imaging AVA

BG 1.3 (0308-0312)
Simulation of borehole acoustic measurements in axisymmetric media with hp-adaptive finite elements
Christian Michler, Leszek Demkowicz, and Carlos Torres-Verdín, U of Texas–Austin

BG 1.4 (0313-0317)
Influence of breakouts on borehole sonic dispersions
Ergun Simsek, Bikash K. Sinha, and Smaïne Zeroug, Schlumberger; Noureddine Bounoua, Sonatrach

BG 1.5 (0318-0322)
Velocity anisotropy and heterogeneity around a borehole

BG 1.6 (0323-0327)
Derivation of anisotropy parameters in a shale using borehole sonic data
John Walsh*, Bikash Sinha, Tom Plona, and Doug Miller, Doug Bentley Schlumberger Oilfield Services; Mike Ammerman, Devon Energy

BG 1.7 (0328-0332)
Reliable small-percentage azimuthal anisotropy evaluation from a new wireline cross-dipole sonic tool: Field examples from U.S., Mexico, and Ukraine
T. Plona, H-P. Valero*, S. Bose, J. Walsh, E. Wielemaker, and P. Saldunbaray, Schlumberger Oilfield Services

BG 1.8 (0333-0337)
Computing borehole modes with spectral method
Florian Karpfinger* and Boris Gurevich, Curtin U of Technology, Perth, Australia; Andrey Bakulin, Shell Int’l E&P
SEG Annual Meeting 2007 news coverage

SEG Technical Program features full slate, new Special Session

Sylvie Dale

23 September 2007—The SEG Annual Meeting Technical Program begins on Monday afternoon with a full slate of 646 accepted papers (505 oral and 141 poster).

This year’s Technical Program is a strong one, commented Bob Hardage, Technical Program Committee chairman. The committee’s task was to pare down the more than 800 abstracts received to 646 oral papers and posters.

"We have to go through a rather rigorous peer review process to go through this," Hardage said. A total of 478 peer reviewers participated in the abstract selection process, and combined with the cochairs and session monitors, that number jumps to about 690 people—more than the number of accepted papers.

"I don’t think there is any other SEG activity that gets that many members involved."

Some more numbers:

/ Accepted papers are from roughly 44 countries around the world.

/ More than 200 students submitted papers.

/ There are 165 accepted student papers, meaning the student is the primary author of the paper (this number does not include students that may be listed as secondary authors).

A new Special Session has debuted this year and, if it goes well, may be a permanent addition. Special Session 2, Science and Technologies, the Horizon and Beyond, is similar in scope to the very popular Special Session 1, Recent Advances and the Road Ahead. They are both suited to a more general audience and deal with cutting-edge technologies and methods of the future.

The Technical Program consists of 63 Technical Sessions scheduled Monday through Thursday with a maximum of 11 concurrent Technical Sessions scheduled at any time during the program period. Topic areas that had high abstract submissions, and thus will have several scheduled sessions, include EM exploration, near-surface and environmental, rock properties, seismic inversion, seismic processing: migration, seismic processing: multiples, and time lapse.

Poster sessions will be effective this year because the layout of the Henry B. Gonzalez Convention Center in San Antonio allows us to distribute posters along the major traffic area between the Exhibit Hall (Floor 1) and the Technical Sessions (Floor 2). It remains to be seen if the expected high rate of foot traffic through the poster area will aid or disrupt poster presentations, but we are hopeful that this decision will return a positive response.

When asked if anything about the submissions surprised him, Hardage said he was surprised the program didn’t receive more papers on what he terms multi-azimuth technology. The technology is new enough that the experts are still working out the proper terms, but in a nutshell, it is a seismic acquisition method using more than one source and more than one vessel and involving multiple tows in the same area.

"It is a red-hot topic for subsalt imaging—arguably the most challenging imaging problem that the industry has in the Gulf of Mexico, and in other areas where subsalt is a big part of the subsurface layers. That’s going to control the destiny of subsalt hydrocarbon exploration for the next decade or so."


7/03/2008
Hardage said it will be a great session and plans to attend it, but it may take some time for the topic to attract a lot of papers because people are probably going to need a little more experience, and there may be some confidentiality issues this early in the process.

The usual topics got a lot of papers, including rock physics, seismic migration, and imaging, potential fields (gravity and EM).

A new no-show policy is being tested this year in San Antonio. The Executive Committee, with guidance from the Technical Program Committee, has voted that oral paper authors must give sufficient notice if they cannot present their paper as scheduled. If they do not, they are barred from consideration for the next two SEG Annual Meeting Technical Programs. SEG leaders are hoping this will reduce gaps in the program when a paper cannot be presented at the scheduled time.

Incidentally, attendees may notice that the Steering Committee has largely the same makeup as that of SEG 2001, which also was held in San Antonio but was interrupted by the passenger jet attacks of 11 September 2001. Because they set up a great program in 2001 but were unable to carry it out, everyone but the general chairman agreed to finish what they started in San Antonio this year. If the attitude of the Technical Program Chairman is any indication, the 2007 meeting should be very successful.

**Expanded Abstracts**

Many of the *Expanded Abstracts* have been posted to the SEG Technical Program Online site. At the conclusion of the Annual Meeting, this site will be taken offline, but the Expanded Abstracts will continue to be available (full text to members and subscribers, and abstract views only to nonmembers) in SEG's Digital Library. The *Technical Program Expanded Abstracts CD* is also available through the Book Mart (booth #659).

Related Link: SEG Annual Meeting 2007 News and Photos Index

SEG Annual Meeting Home Page


7/03/2008
The Society of Exploration Geophysicists... Make the Choice and Reap the Benefits

Founded in 1930, the Society of Exploration Geophysicists promotes the science of geophysics and the education of exploration geophysicists. SEG fosters the expert and ethical practice of geophysics in the exploration and development of natural resources, in characterizing the near-surface, and in mitigating earth hazards. With more than 25,000 members worldwide, the Society is committed to the dissemination of geophysical knowledge among its members, with continuously improving professional practice as its goal.

Key Membership Benefits:

1. Publications: All members receive access to the SEG Digital Library, which includes Geomicrobes, The Lease 2002, SEG Technical Program Expanded Abstracts, and Robert E. Sheriff's Encyclopedic Dictionary of Applied Geophysics, fourth edition. All members also receive the SEG Yearbook on a CD-ROM that also includes the previous year's articles from Geosciences and TLE. Most members receive TLE in print, and Geosciences in print is available to members at a modest subscription rate.

2. Reference Publications discounts: Members may purchase SEG books at a substantial discount off list price.

3. Annual Meeting discount: Members receive major discounts on registration fees for the SEG Annual Meeting.

4. Professional Development: Members obtain essential training in geophysics and career-enhancing skills at special membership prices.

5. Networking: SEG meetings and courses provide outstanding opportunities for geoscience professionals to network with their associates in academia and industry. Members also enjoy interaction with the pros through geographic sections and special-interest committees.

6. MySEG: This suite of services includes an online messaging and collaboration tool that enables committees and other member groups with common interests to share ideas. MySEG also includes a robust member search engine and access to special pricing on a variety of SEG products and services.

7. Employment: Members in career transition obtain assistance through SEG Employment Referral. Job seekers may post resumes on SEG's Web site and in a specified area at the Annual Meeting. Employers can use the same resources to post job opportunities.

8. Group Insurance: SEG, in partnership with the American Association of Petroleum Geologists, offers health and life insurance coverage to members. For more information, visit www.groupbenefits.com